Center for Particle Astrophysics

Fermilab

DARK ENERGY SURVEY

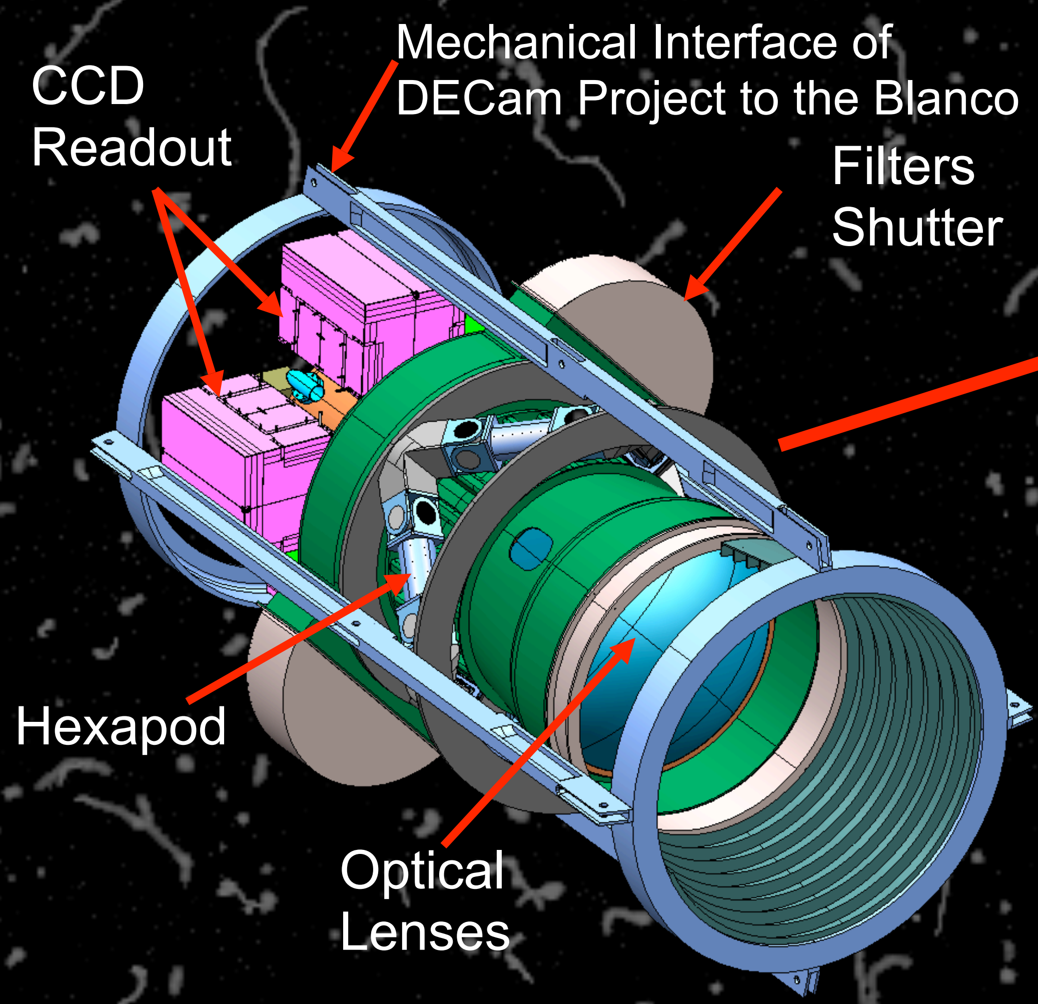
CCDs for the Dark Energy Camera

Juan Estrada for the DES Collaboration

9/24/2008

Dark Energy Camera (DECam)

New wide field imager (3 sq-deg) for the Blanco 4m telescope to be delivered in 2010 in exchange for 30% of the telescope time during 5 years. Being built at FNAL.

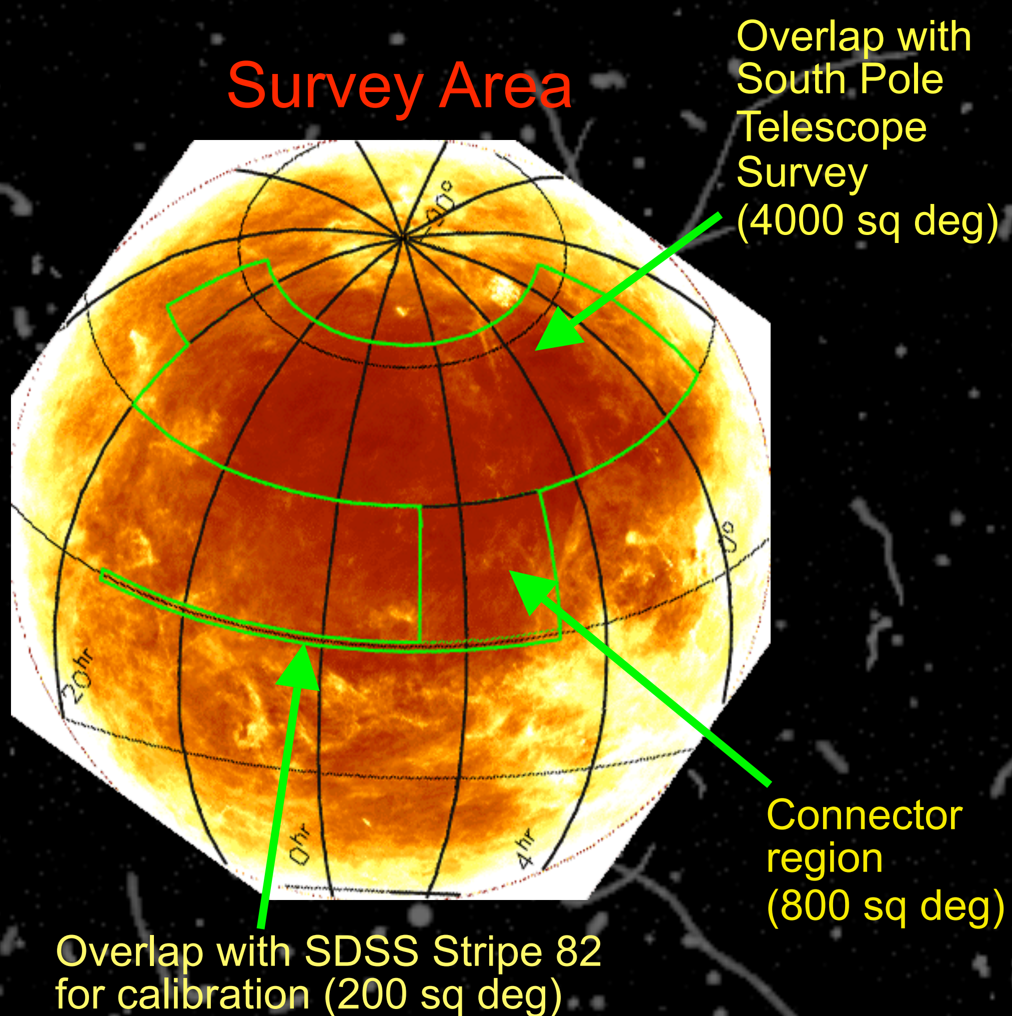


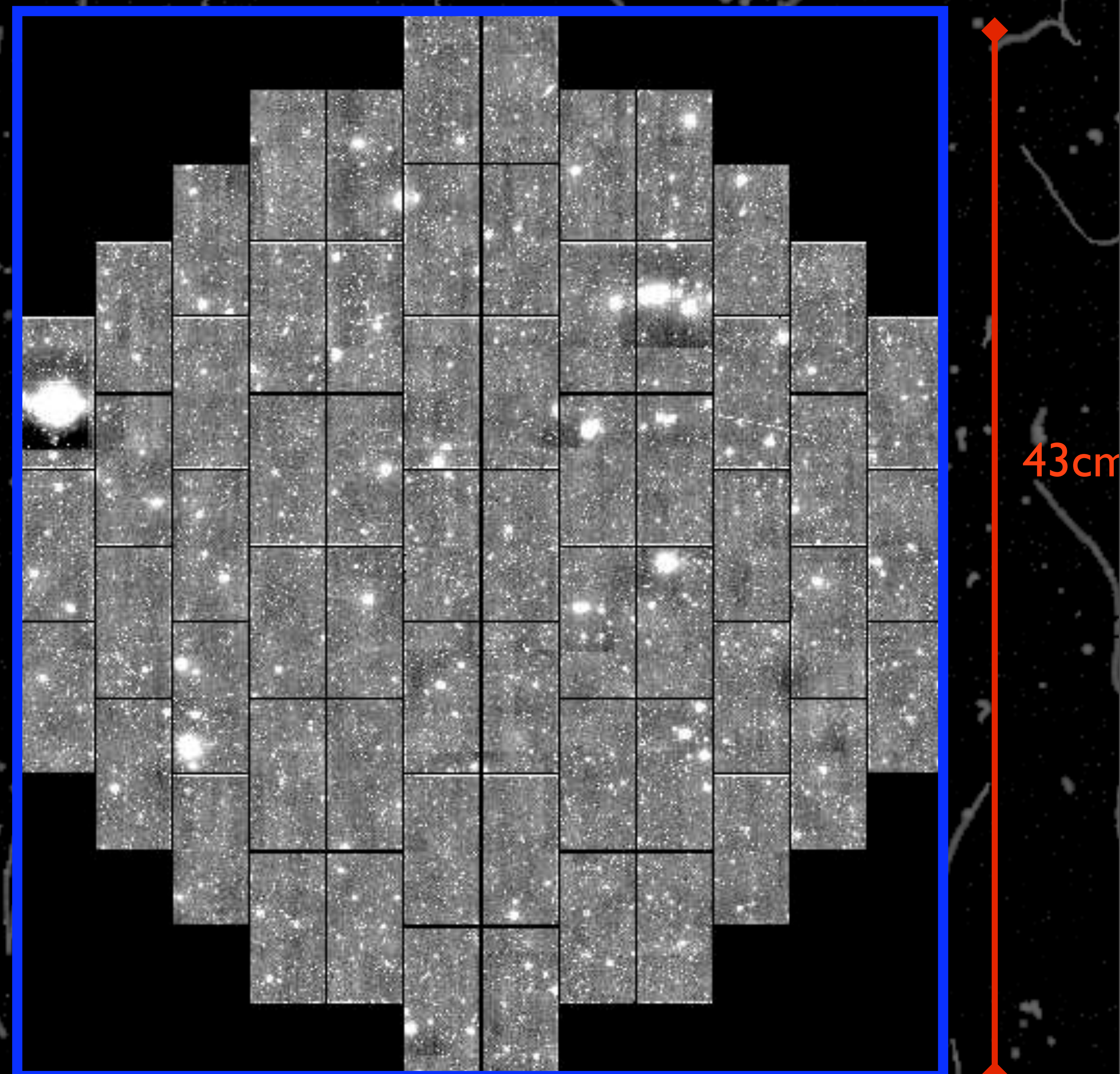
For those of you who understand what it means, we have been recommended for CD3b. If you do not understand what this means, you should feel proud of yourself.

Dark Energy Survey

optimized to measure the equation of state parameter w for Dark Energy. Relation between pressure and density.

Survey Area





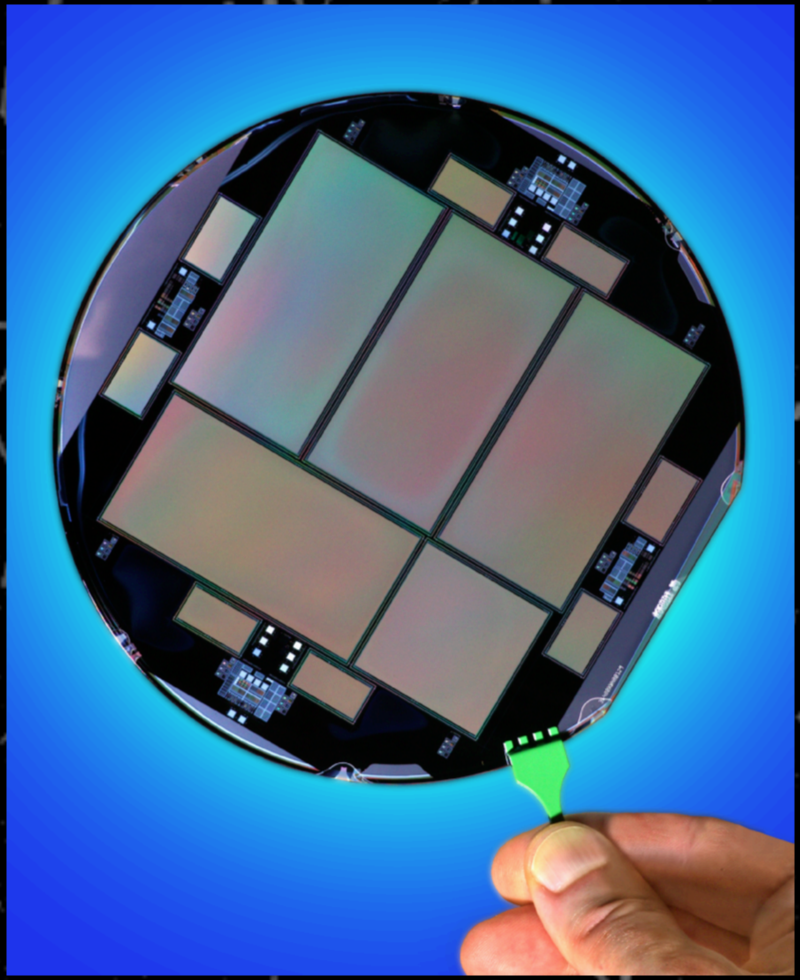
Galaxy Cluster counting
(collaboration with SPT, see next slides)
20,000 clusters to z=1 with $M>2\times10^{14}M_{sun}$

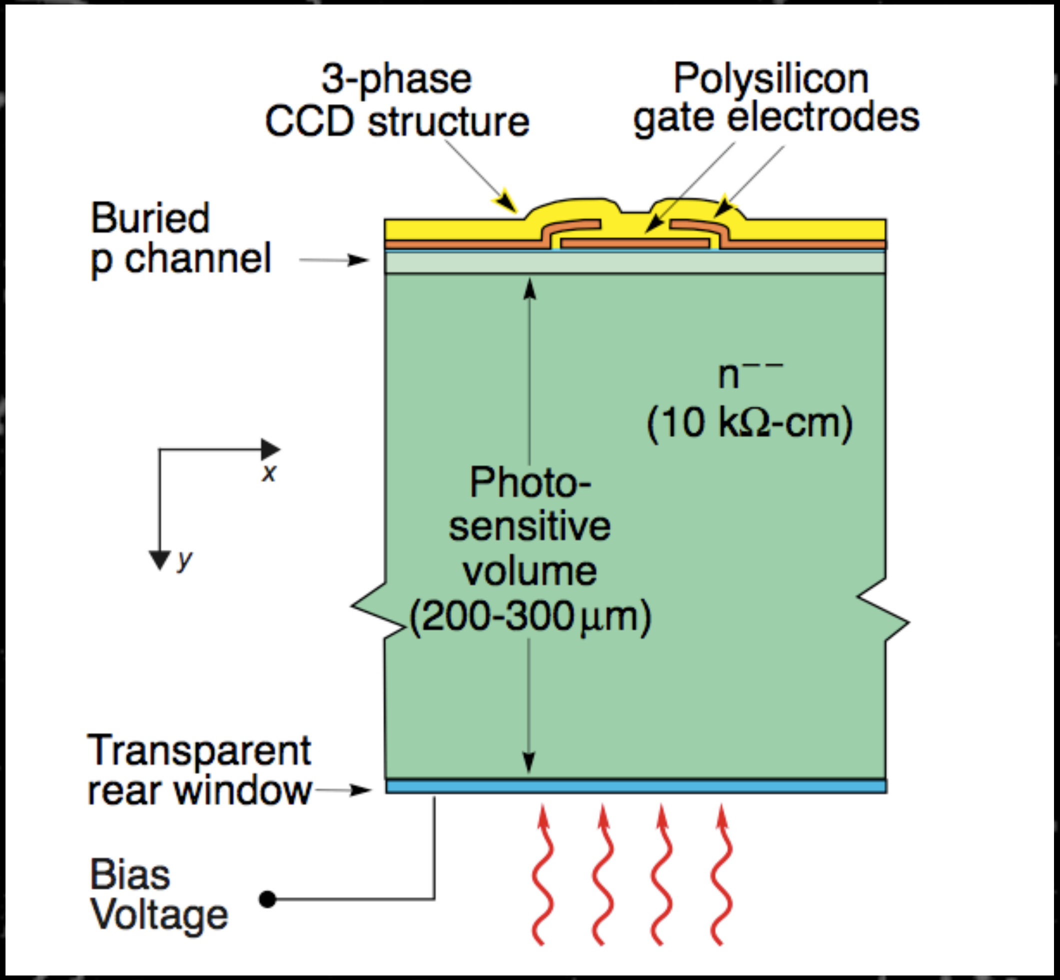
Spatial clustering of galaxies (BAO)
300 million galaxies to z ~ 1

Weak lensing
300 million galaxies with shape measurements over 5000 sq deg

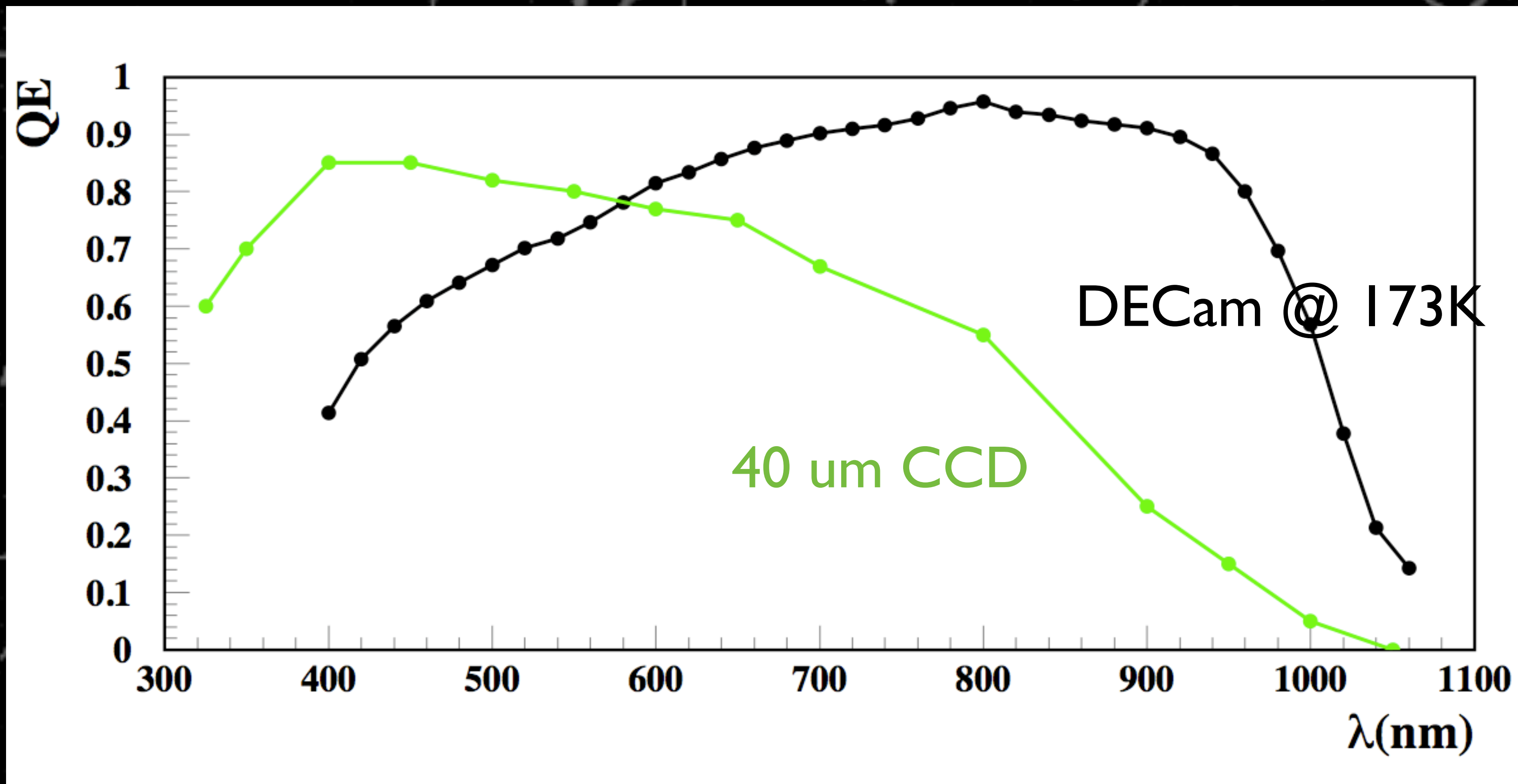
Supernovae type Ia (secondary survey)
~1100 SNe Ia, to z = 1

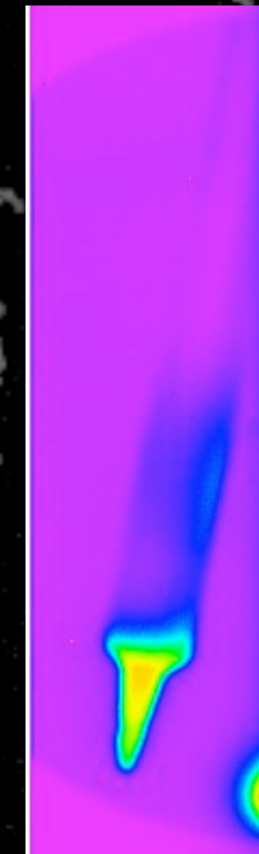
DECam CCDs





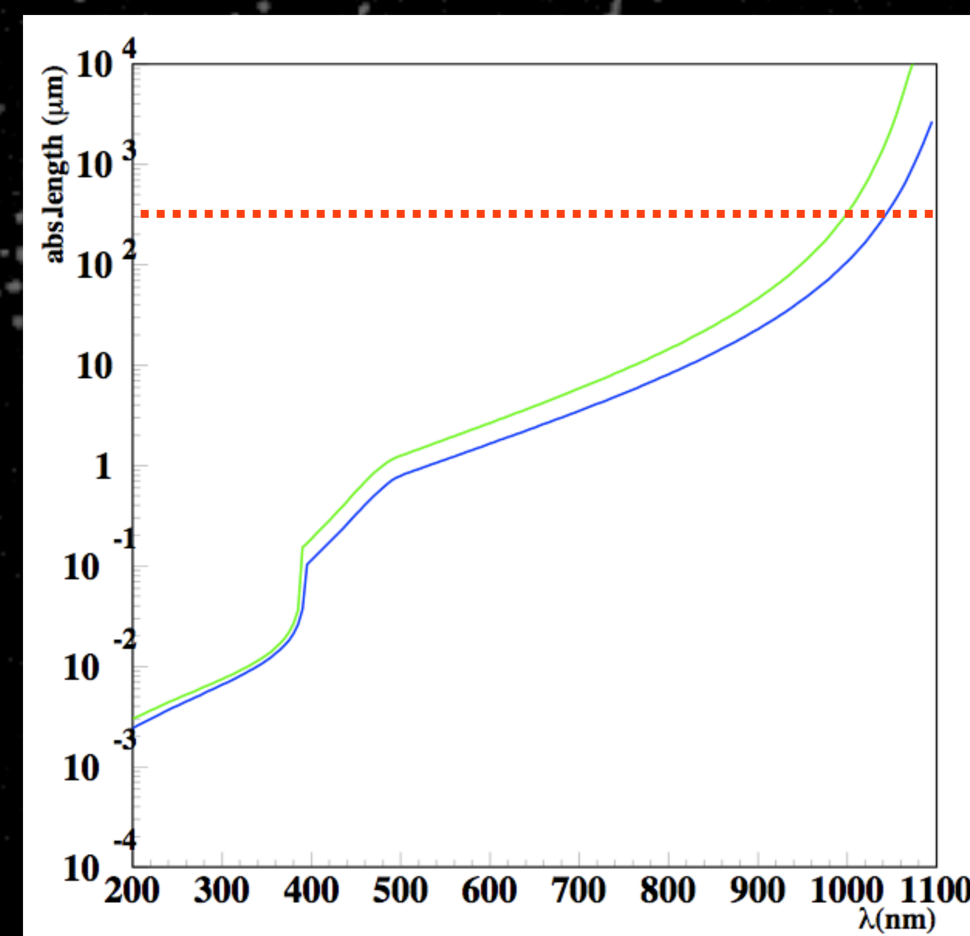
250 µm thick fully depleted
hi-resistivity p-channel technology developed by LBNL
15 µm x 15 µm pixels
operating temperature : -100 C





Soldering iron IR imaging with DECam CCD. 20 seconds exposure with a narrow (10nm) filter centered at 810nm.

250 μm thick fully depleted produces a higher efficiency in the near-IR



CCD technical requirements and testing

	LBNL CCD Performance	DECam Requirements	Technical Specification
Pixel array	2048 × 4096 pixels	2048 × 4096 pixels	
Pixel size	15 μm x 15 μm	15 μm x 15 μm	
# Outputs	2	2	
QE(g,r,i,z)	70%, 90%, 90%, 75%	60%, 75%, 60%, 65%	TD.7
QE Instability	Stable	<0.3% in 12-18 hrs	TD.8, TD.9
QE Uniformity in focal plane	uniform	<5% in 12-18 hrs	TD.10, TD.11
Full well capacity	170,000 e^-	>130,000 e^-	TD.2
Dark current	2 e^-/hr/pixel at 120°K	<~25 e^-/hr/pixel	TD.5
Persistence	Erase mechanism	Erase mechanism	TD.3
Read noise	7 e^- @ 250 kpixel/s	< 15 e^- @ 250kpix/s	TD.4, TD.12
Charge Transfer Inefficiency *	$< 10^{-6}$	$<10^{-5}$	TD.6
Charge diffusion	6-7 μm	1D σ < 7.5 μm	TD.13
Cosmetic Requirements		<# Bad pixels> <0.5% Similar to E2V grade 0	TD.16
Linearity	Better than 1%	1%	TD.1
Package Flatness	< 10 μm	See text.	TD.14,TD.15

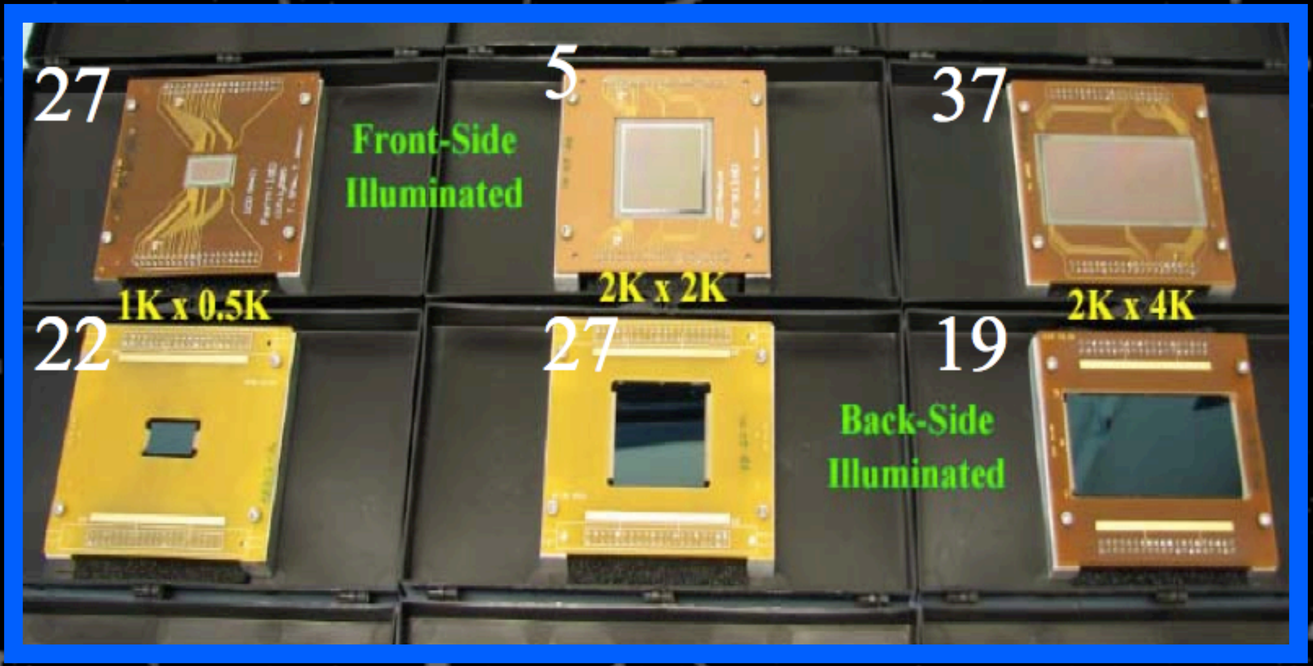
* poster CTI performance by Derek Thompson

Stage 1: Tested the first day and aoutomated report produced overnight.

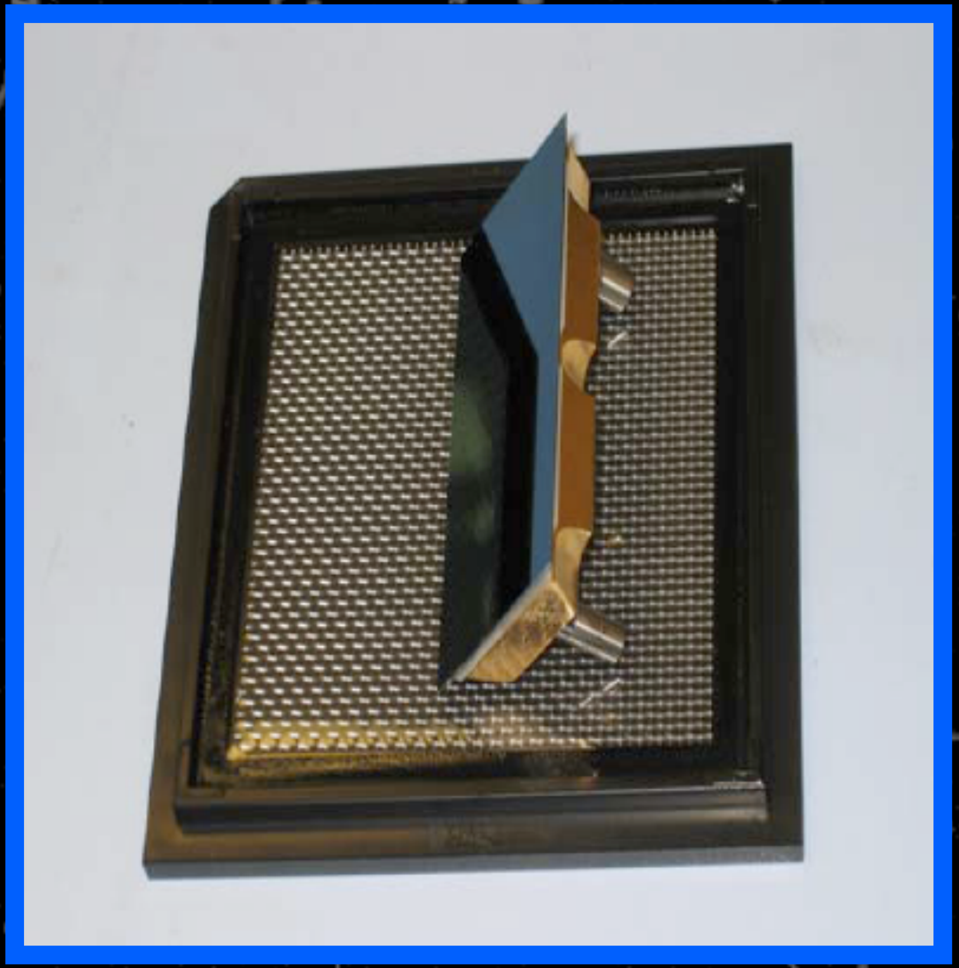
Stage 2: Tested the first week for detectors that pass stage 1.

see poster for automated testing description by Donna Kubik.

DECam CCD Packaging

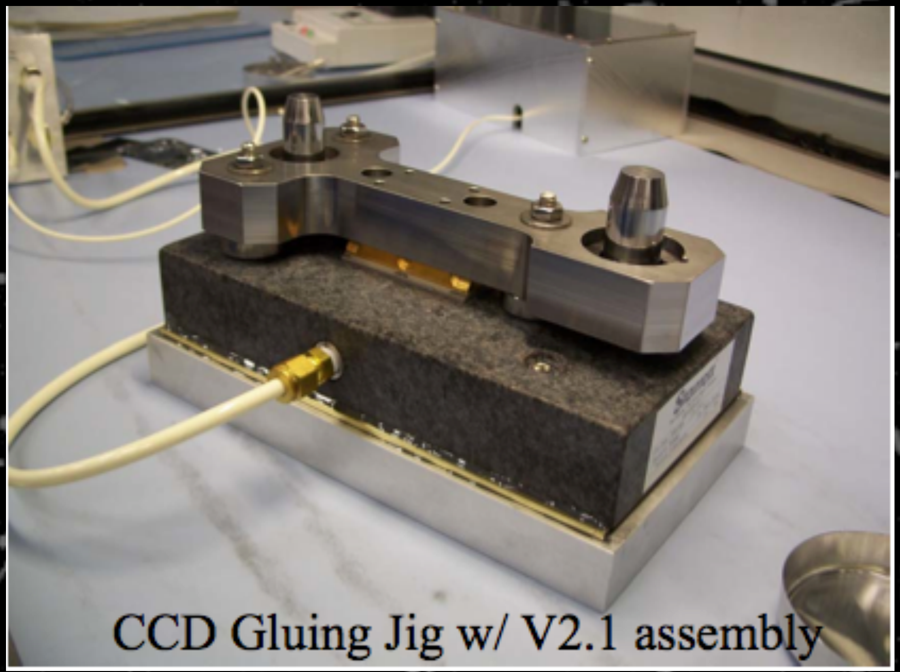


For the R&D stage ~150 engineering detectors packaged in picture frame

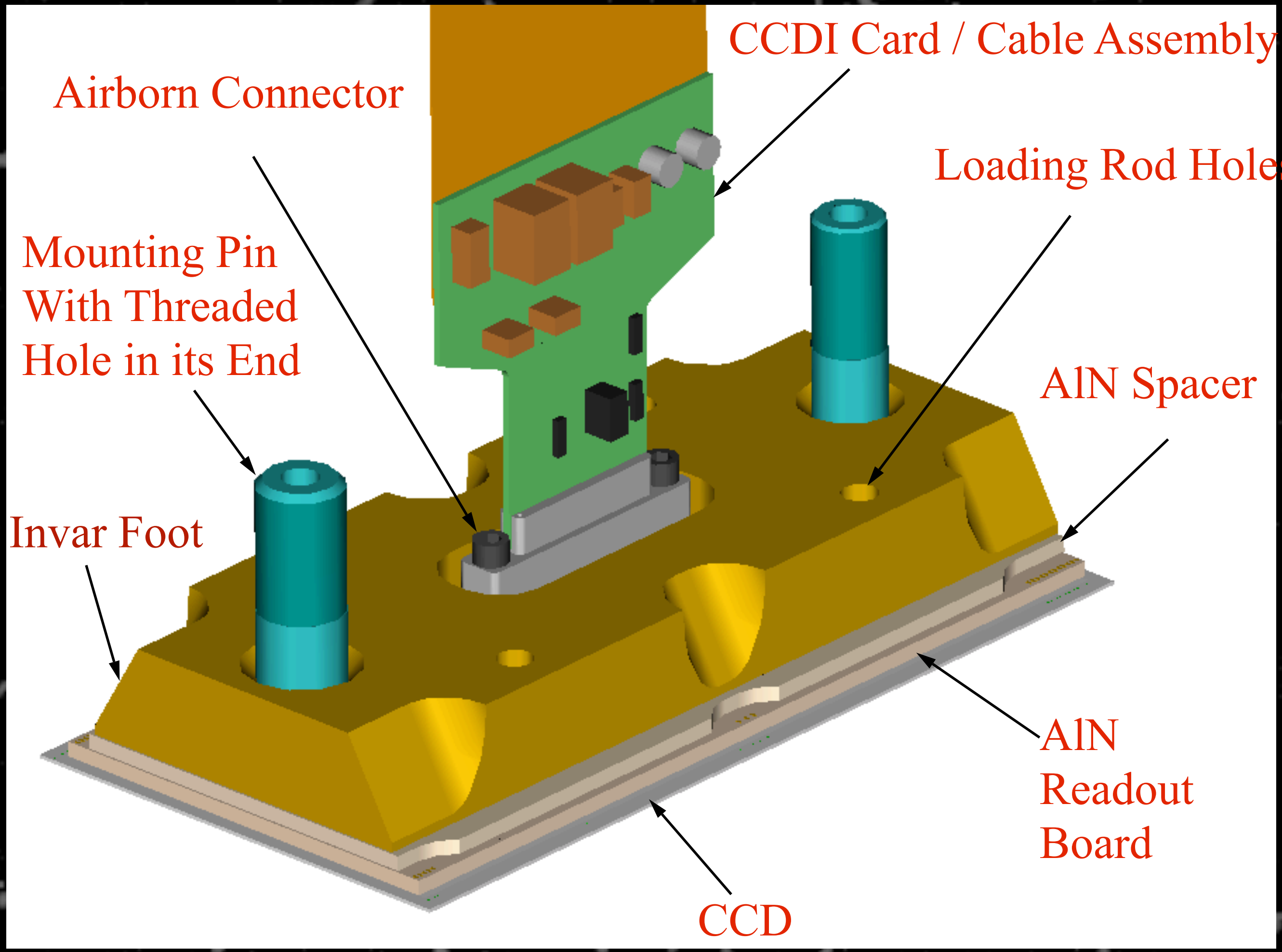


science module

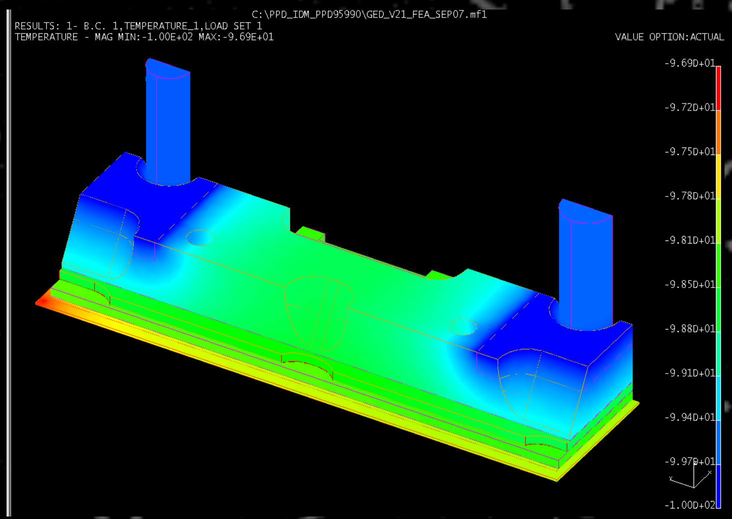
Science module



CCD Gluing Jig w/ V2.1 assembly

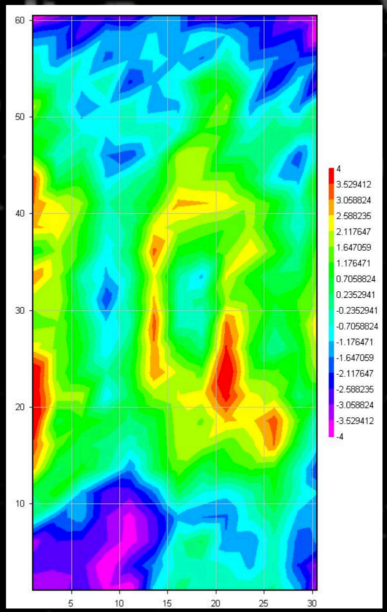


critical assembly step: attaching the CCD to the AlN board. This is done by flowing epoxy between the two parts in a fixture that keeps the them fixed and the CCD flat.

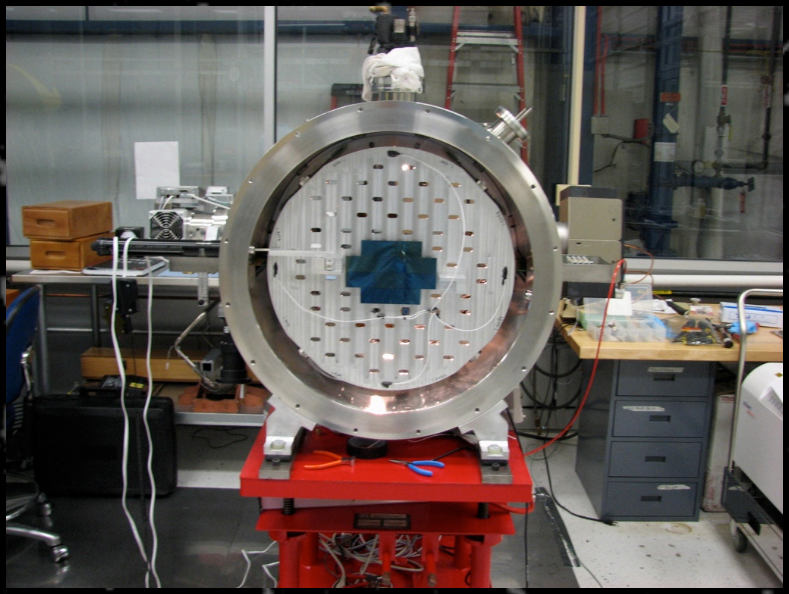


finite element analysis to control thermal and mechanical properties for the package design.

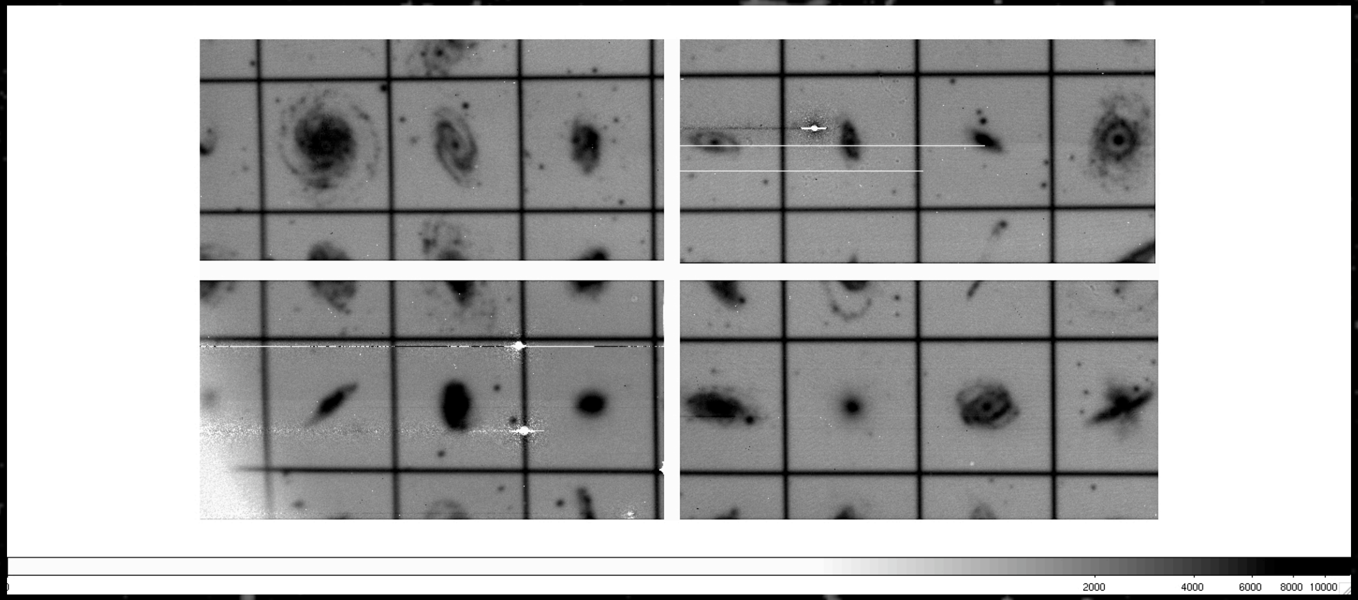
Flatness measurements done on the cold package, it is flat to 10μm.



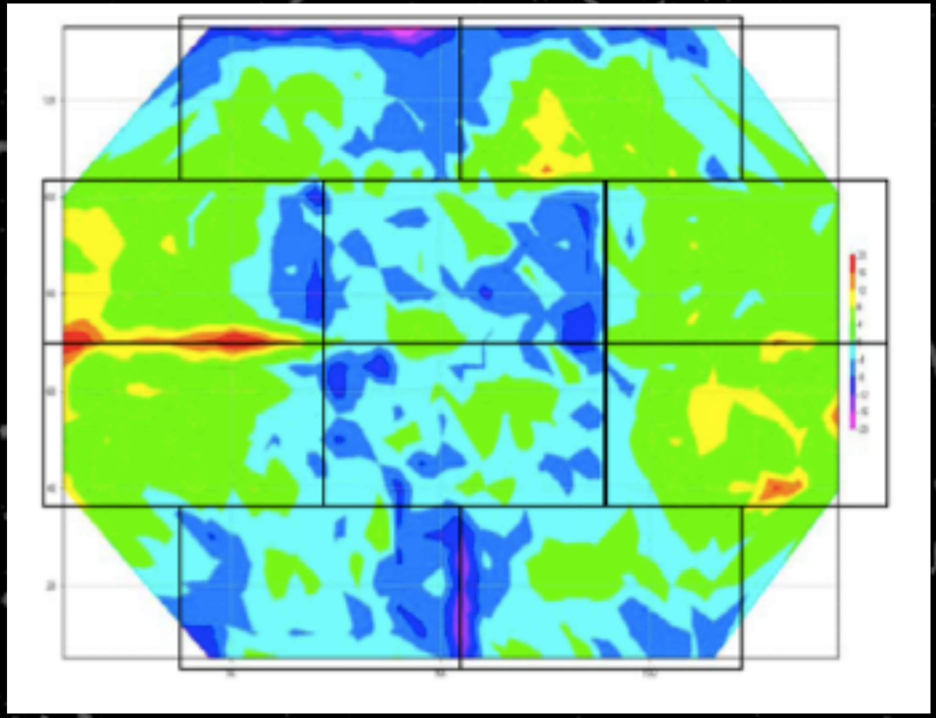
System Tests



Full size prototype in operation, with partially filled focal plane.



pinhole imaging with prototype mosaic

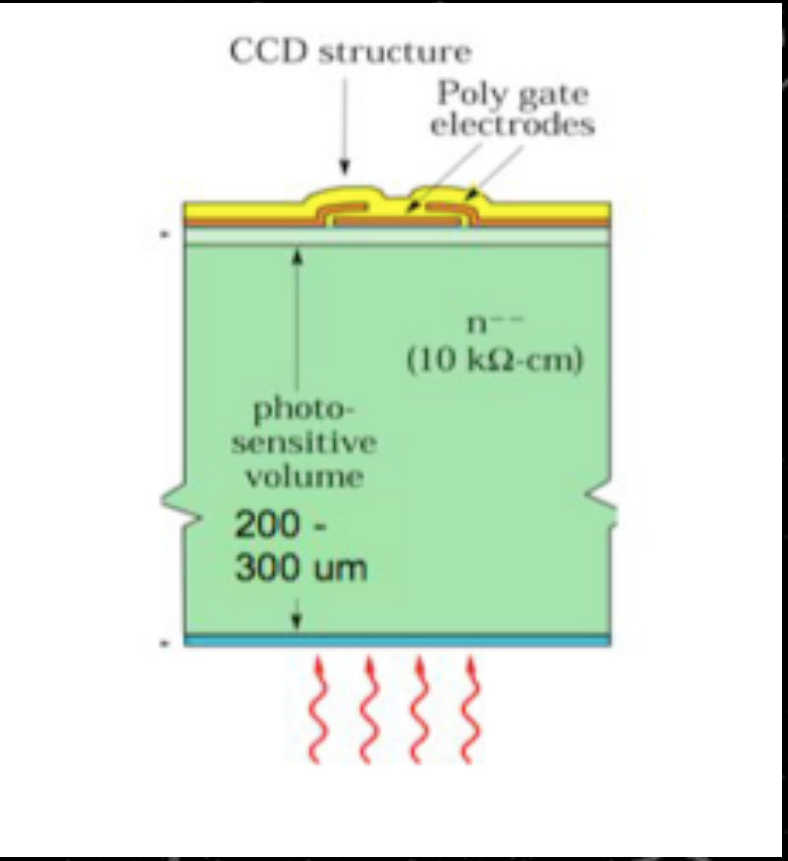


flatness measurements done, flat to 10 µm. Temperature difference between detectors < 2 C.

Readout electronics developed for the large mosaic currently under test. **See posters by Julia Campa and Laia Cardiel.**

A few measurements of the performance for these detectors.

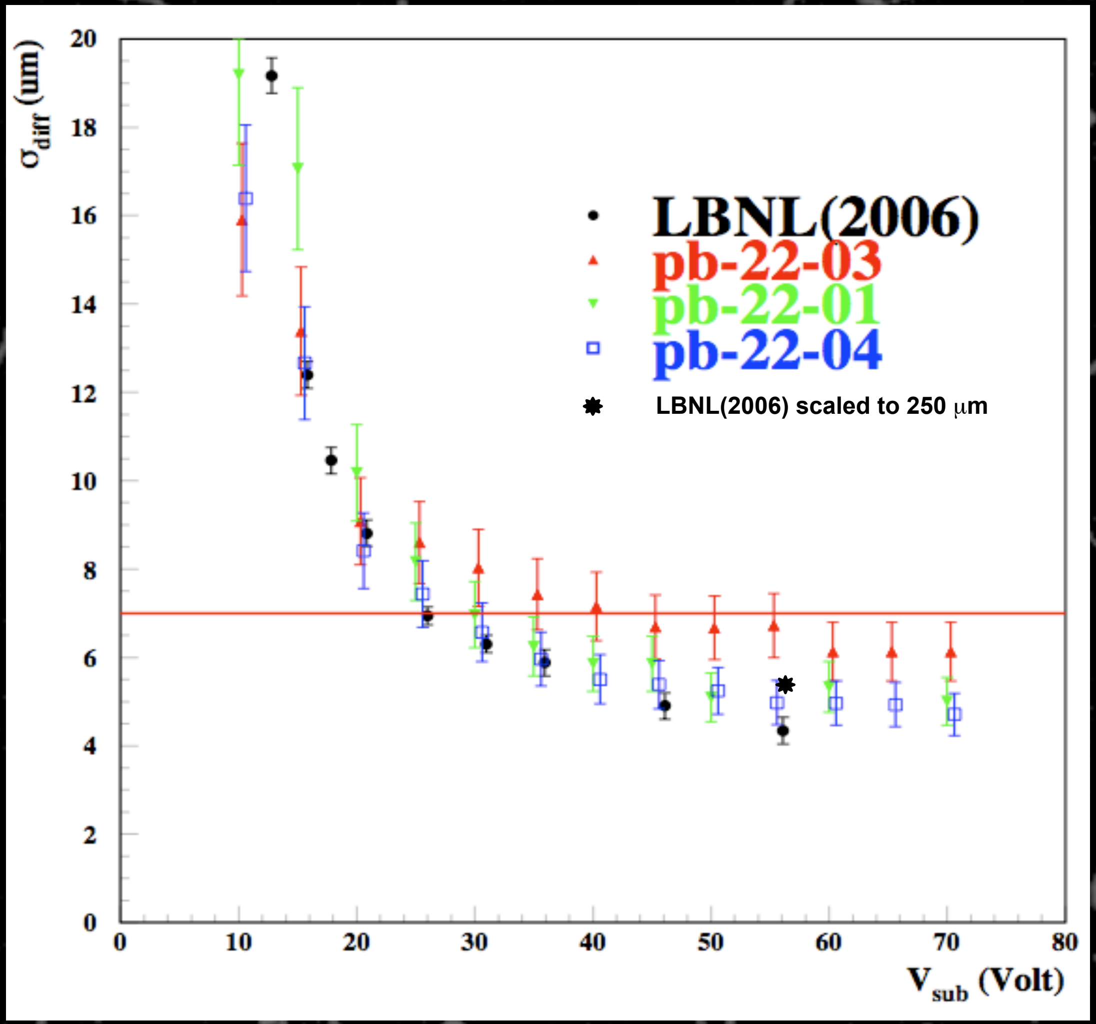
Diffusion by diffraction



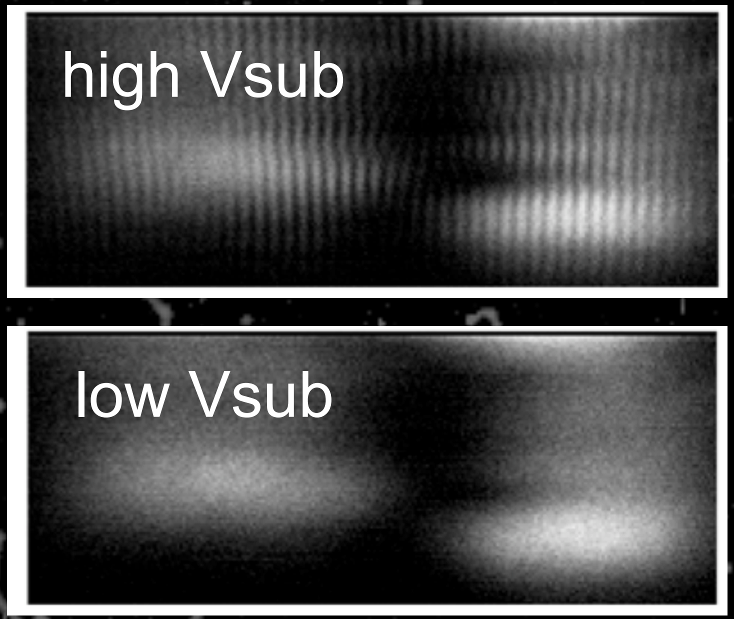
Thicker detectors have more opportunity for lateral charge diffusion.

40V applied to the substrate (Vsub) to control diffusion.

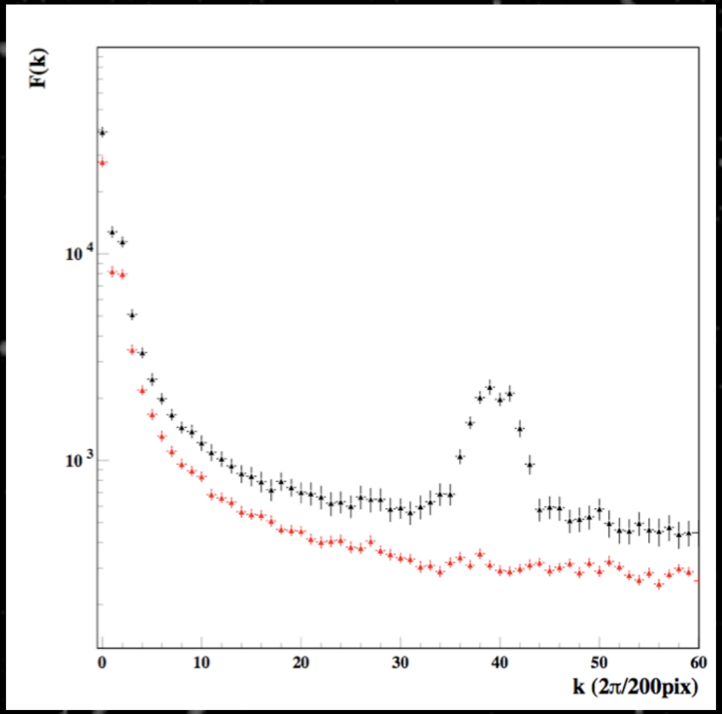
Diffusion could reduce your signal to noise, is bad!



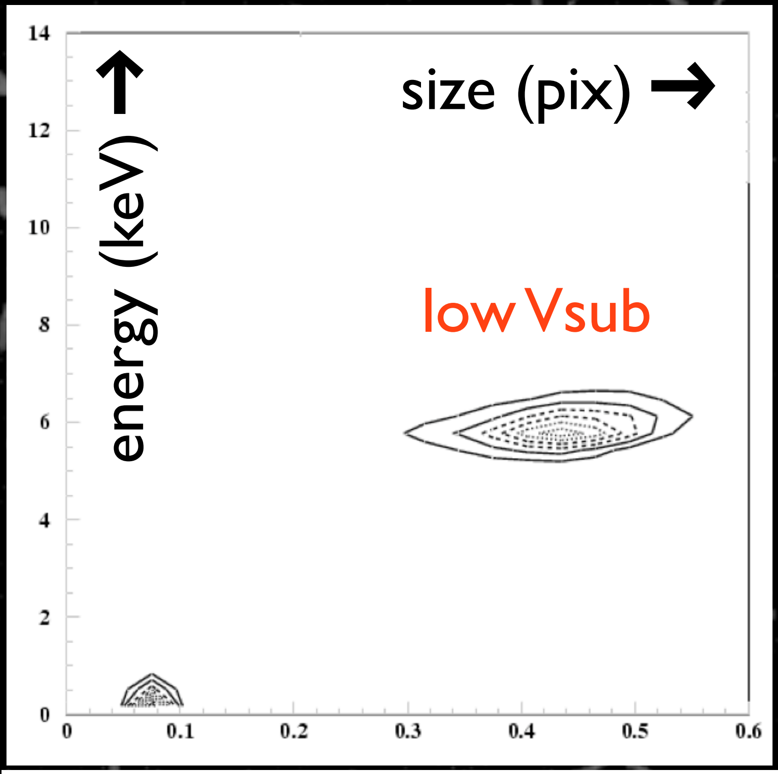
Imaging of a diffraction pattern

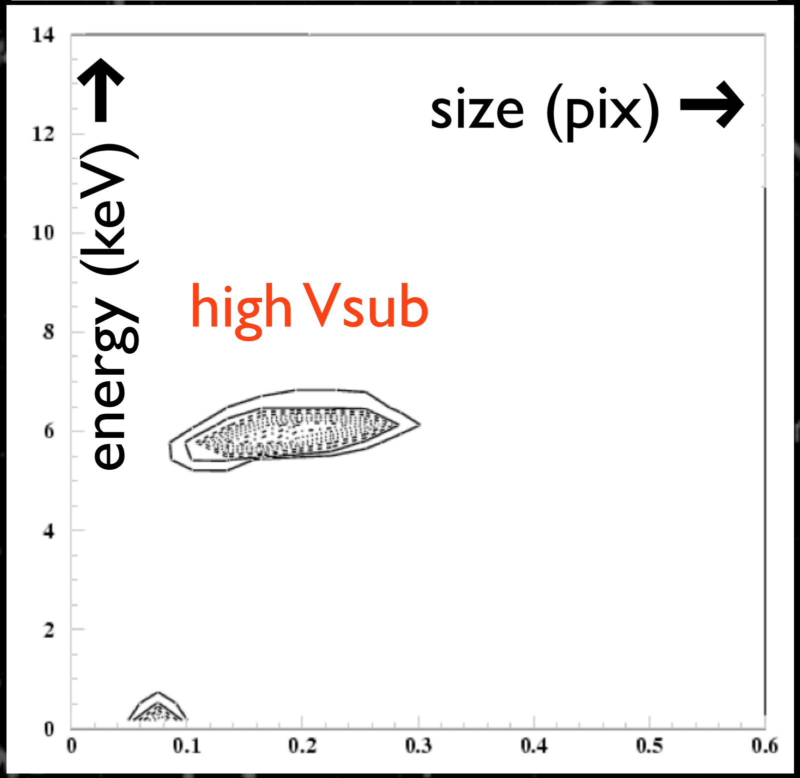


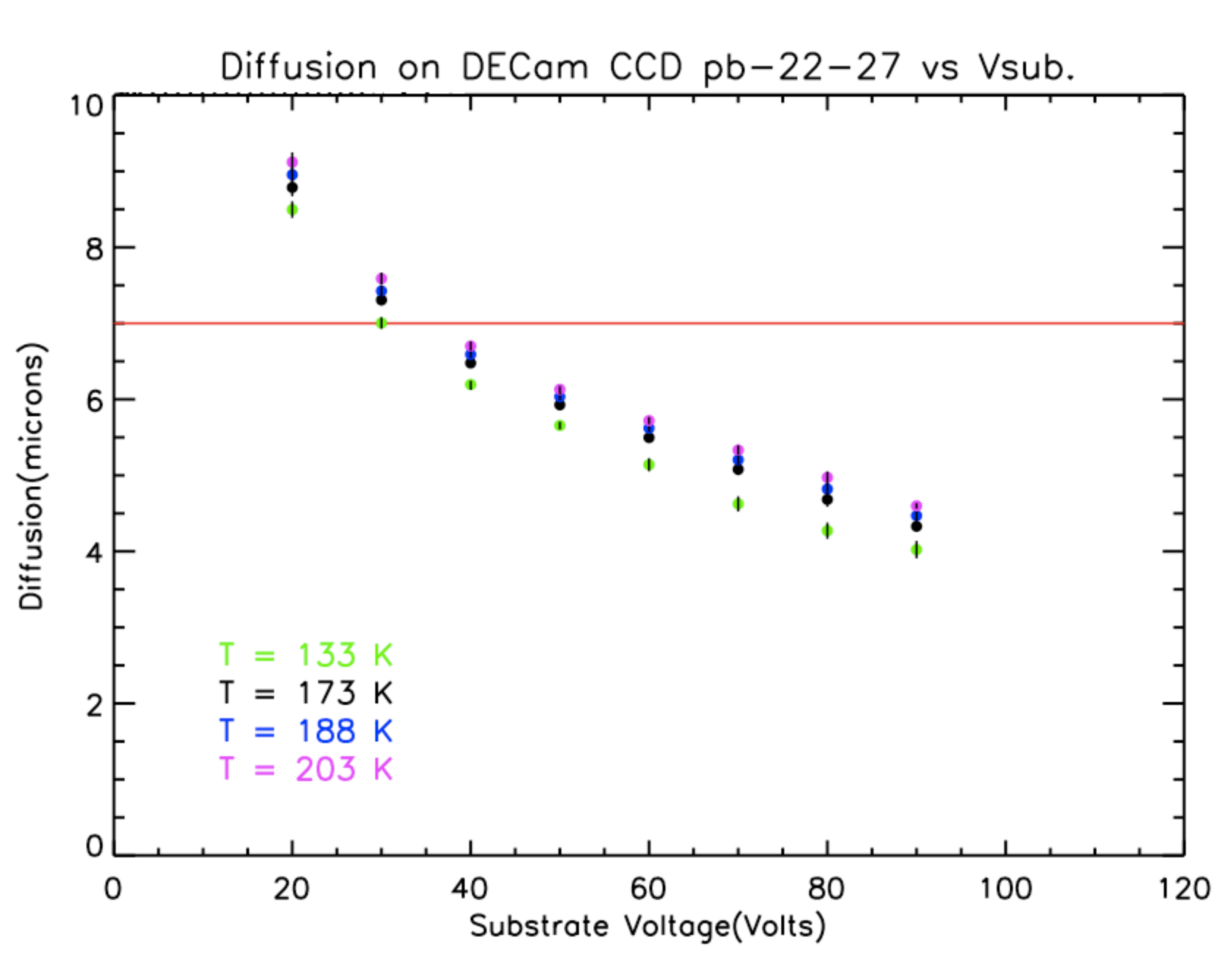
Diffusion is measured from the analysis of these images



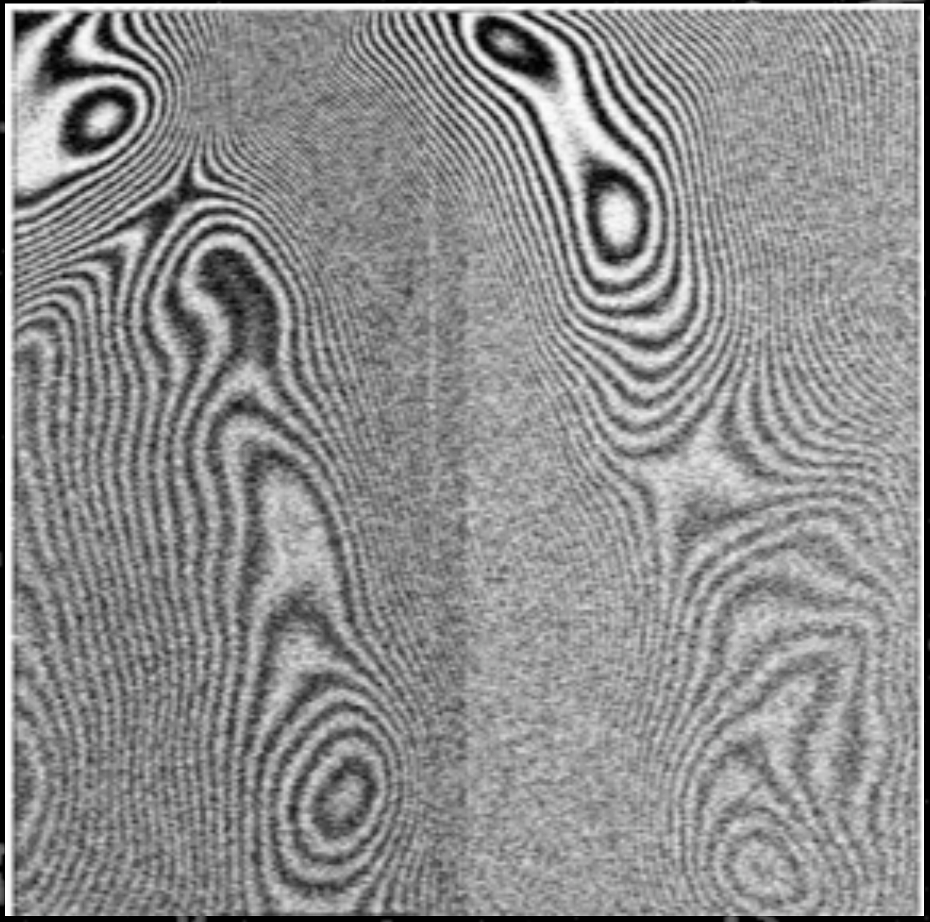
Diffusion with X-rays



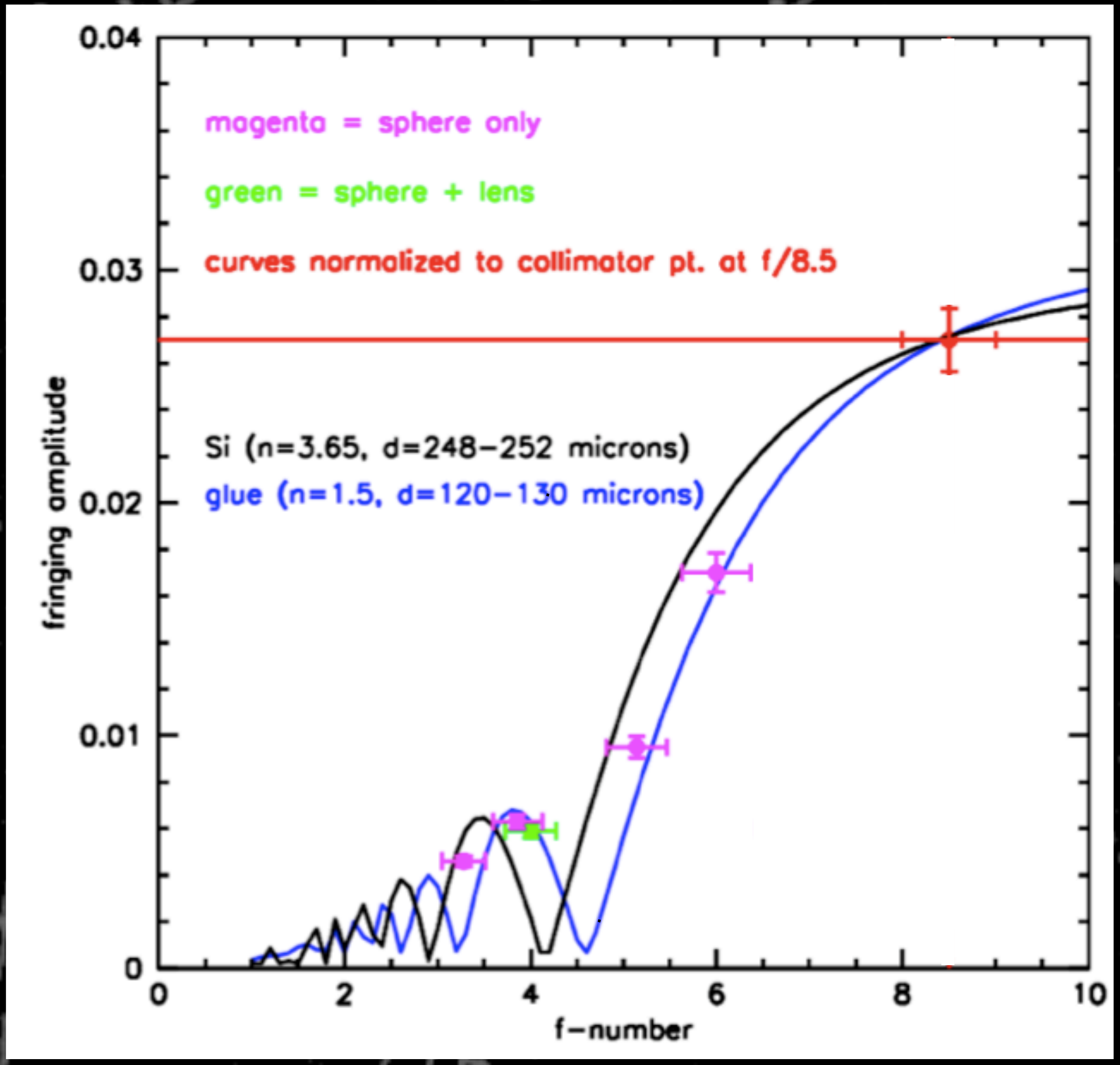




Fringing



Silicon detector become mostly transparent in the IR. I**nterference pattern due to multiple reflections in the front and back of the CCD.** This thicker detectors have less of a problem here, but if you have a narrow enough line you can still see the effect.



Measurements done in our lab indicate a 0.5% QE variation due to fringes in a f/3 system like DECam. (Ar lamp, 980nm line)

Big improvement over thinned detectors

DECam CCDs as particle detectors

5.9 keV X-ray from Fe55 give 1620e-

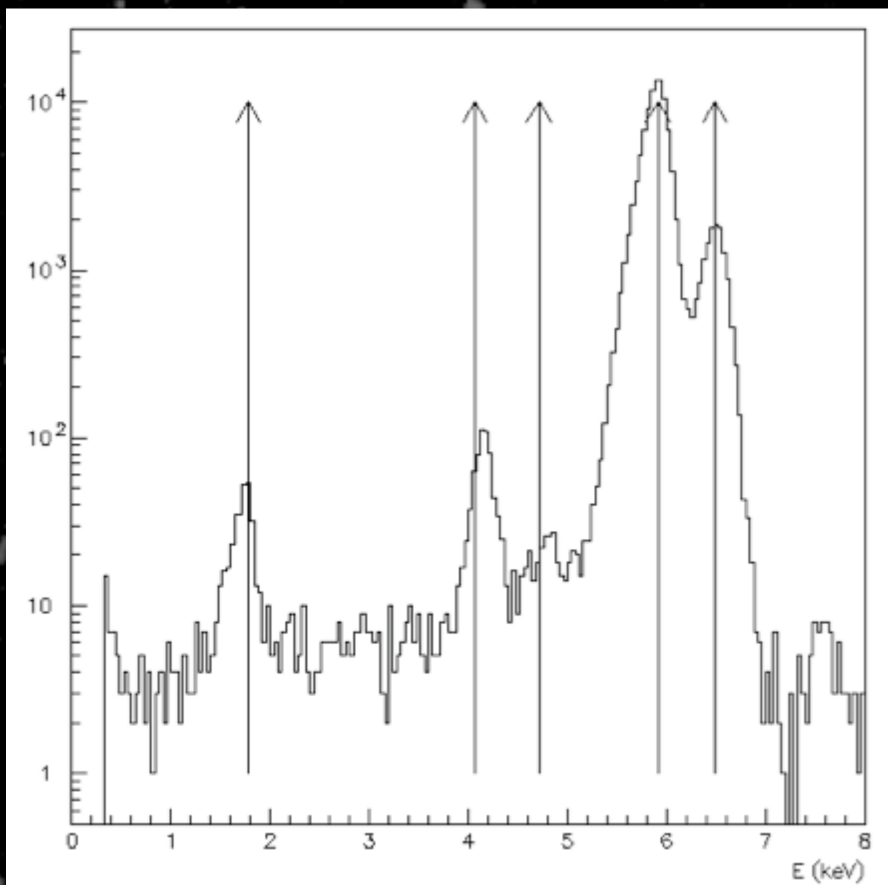
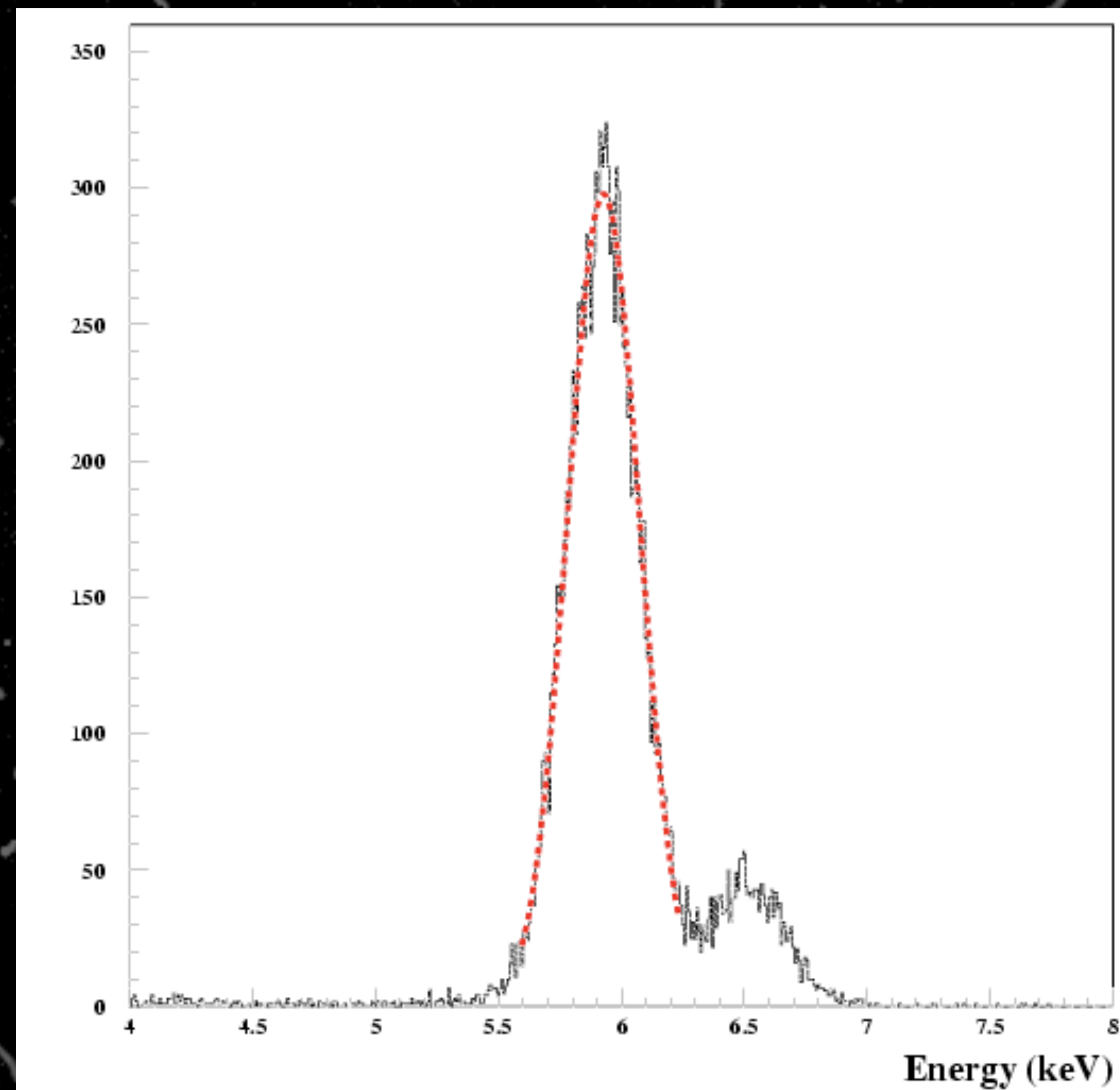


FIG. 4: Spectrum obtained for the reconstructed X-ray hits in an ^{55}Fe exposure of a DECam CCD. The arrows mark the direct X-rays from the source Kα=5.9 keV and Kα=6.5 keV, the Kα and Kβ escape lines at 4.2 and 4.8 keV, and the Si X-ray at 1.7 keV. The factor 3.64 eV/e is used to convert from charge to ionization energy.

Energy resolution

0.15 keV = 41 e- = sqrt (1620e-)

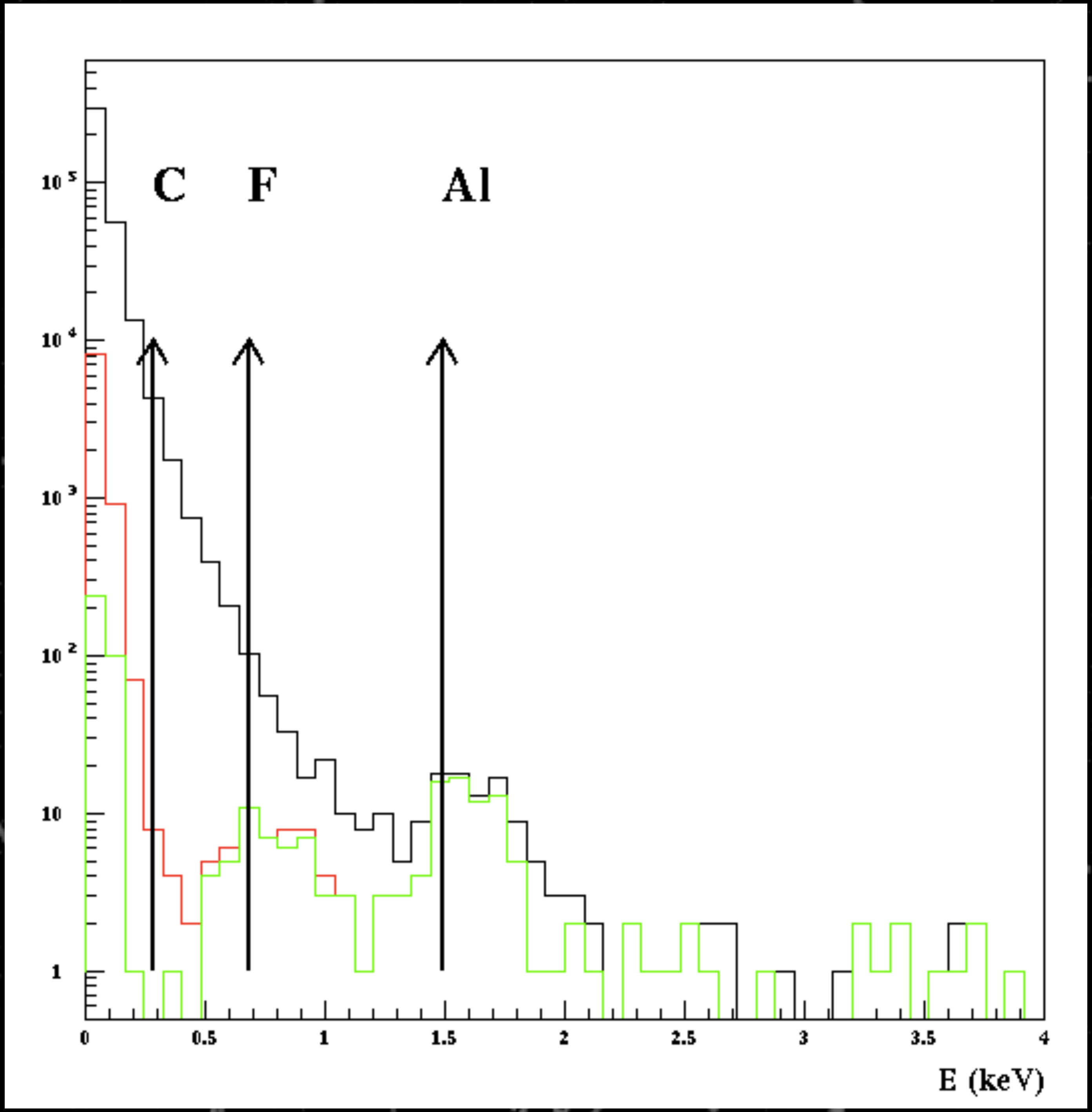


more X-rays

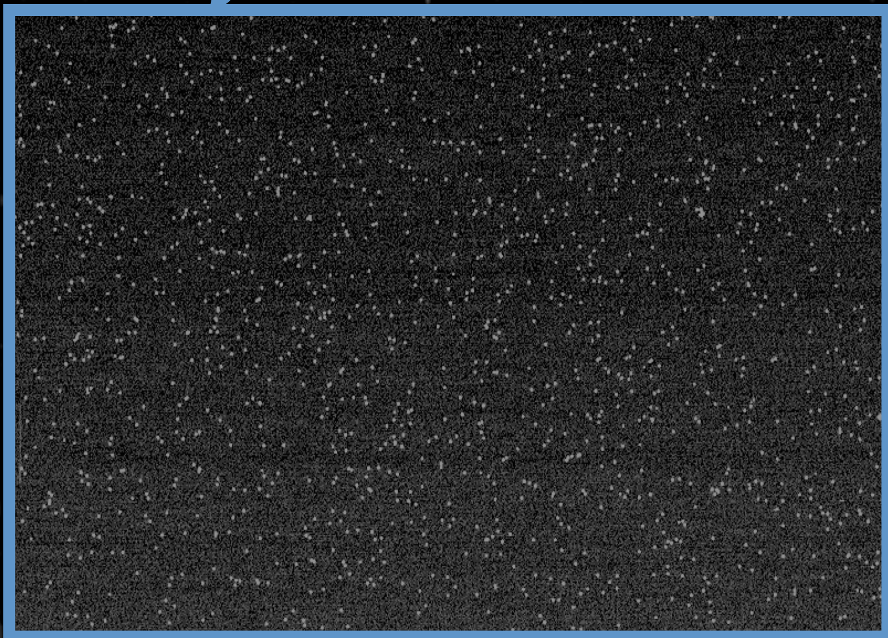
With the Fe55 X-rays hit a teflon or Al and produce lower energy X-rays for study of the diffusion in the first few microns on the back side (important for UV image quality)

expected lines:

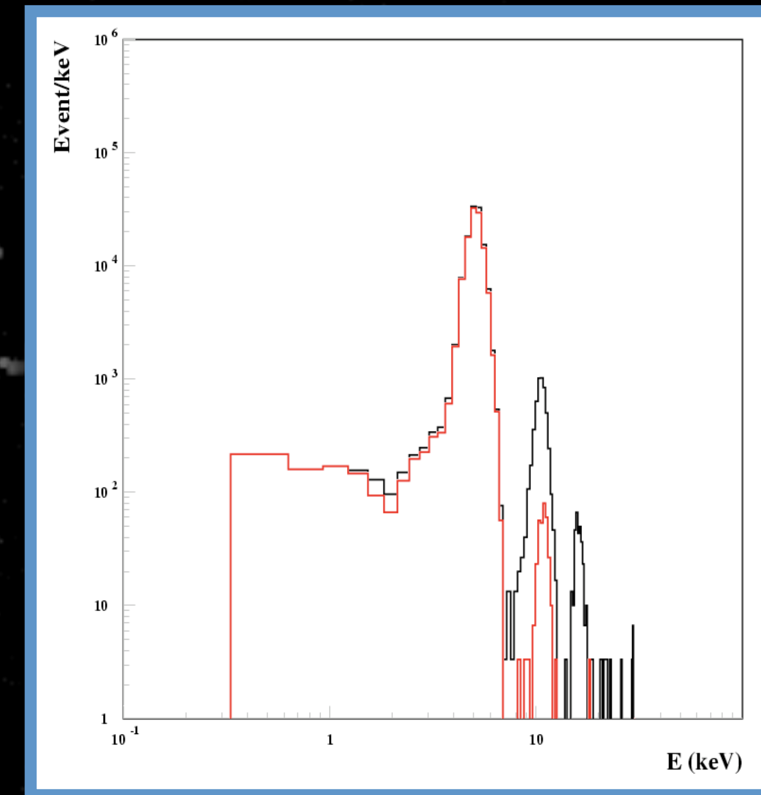
C =0.28 keV (not seen)
F =0.68 keV
Al =1.49 keV



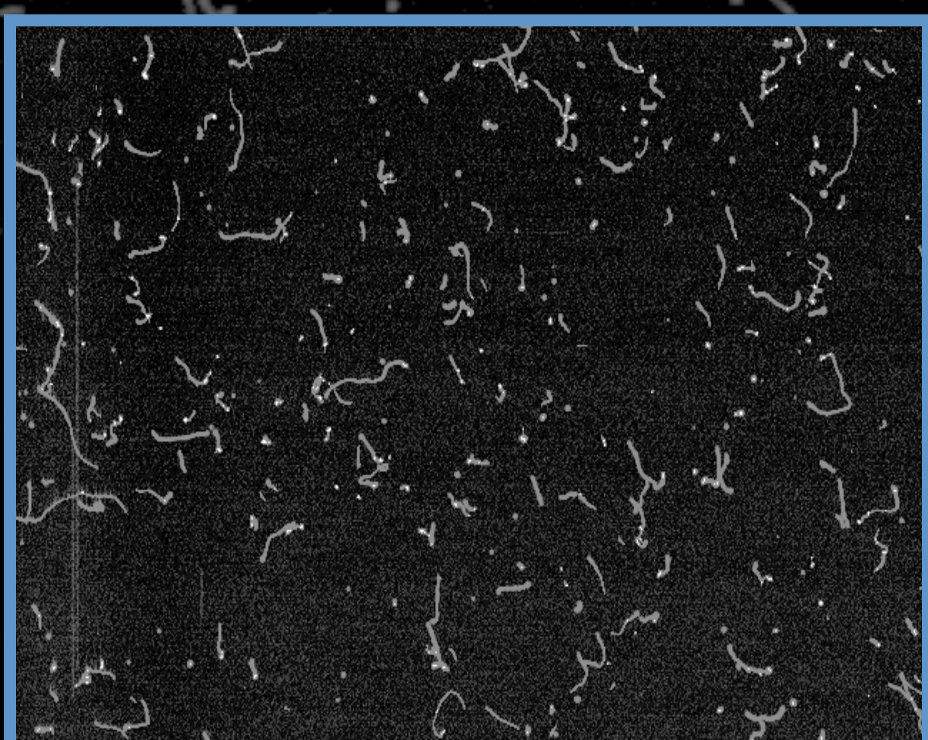
X-ray ^{55}Fe (5.9 keV)



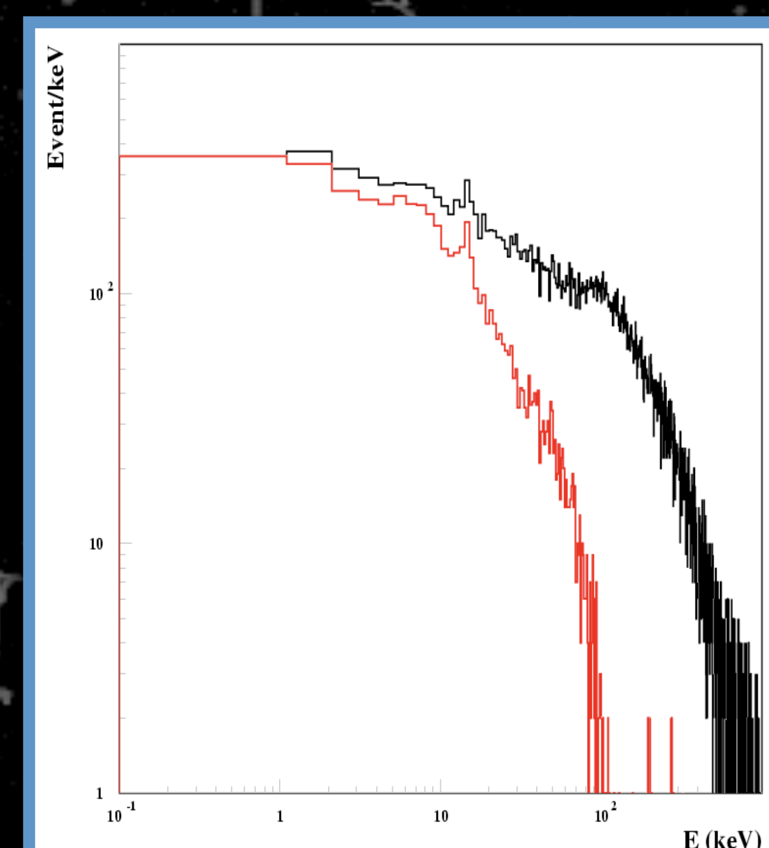
point like hits
(diffusion limited)



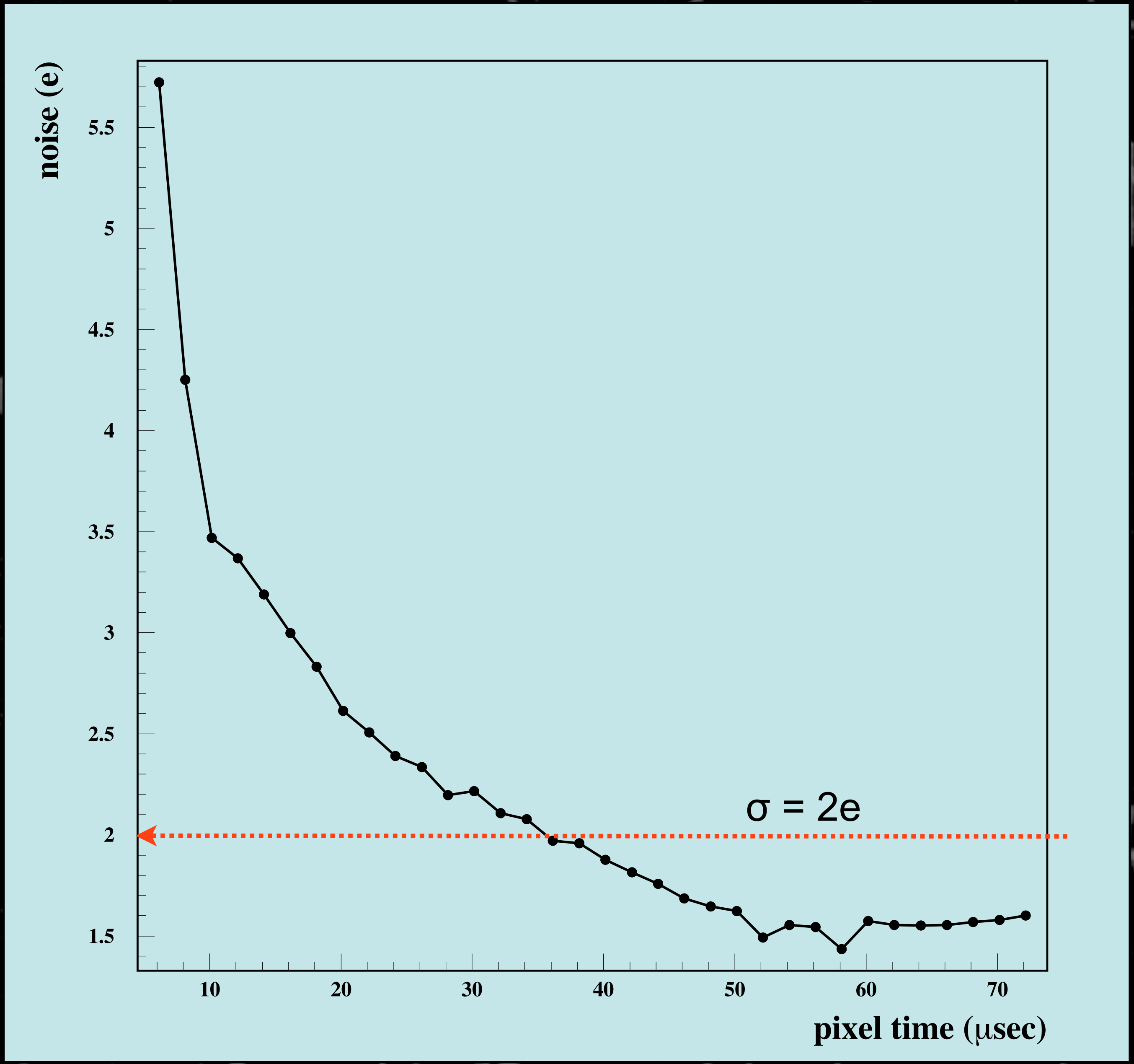
Gammas ^{60}Co (1.33 & 1.77 MeV)



Compton
electrons
(worms) and
point like hits.



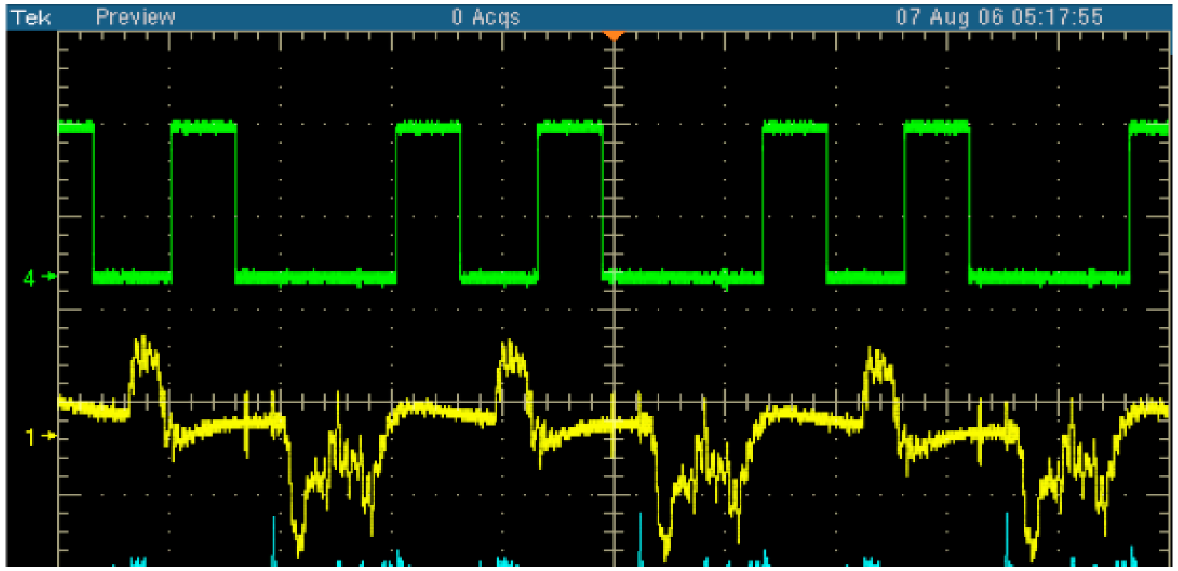
Readout Noise



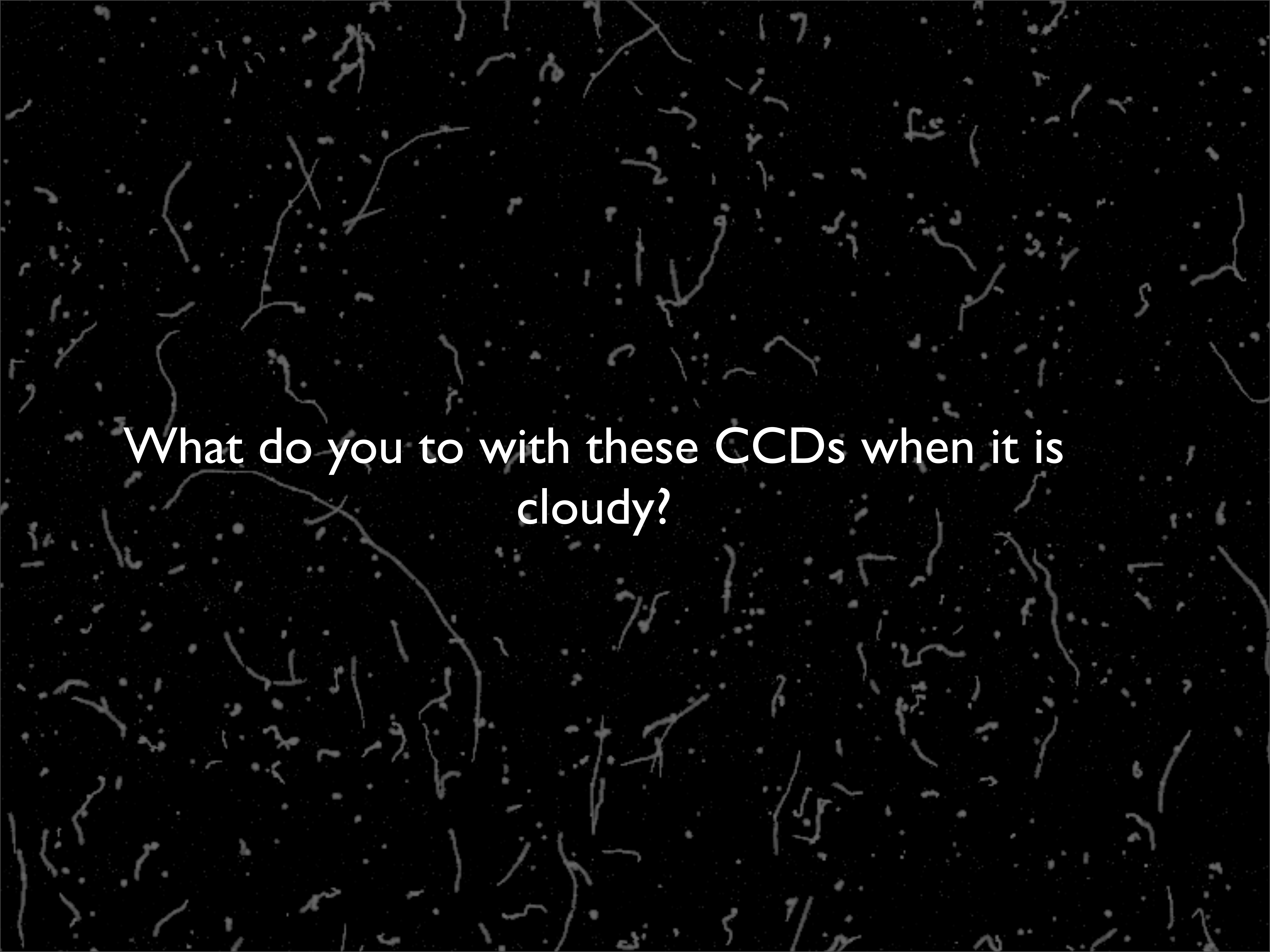
CCDs are readout serially. For DECam we have 17 seconds to do this (250 kpix/sec) and we get ~8e of noise.

But you could go really slow and reduce the noise further.

CDS: Video is sampled with 2 integration windows.

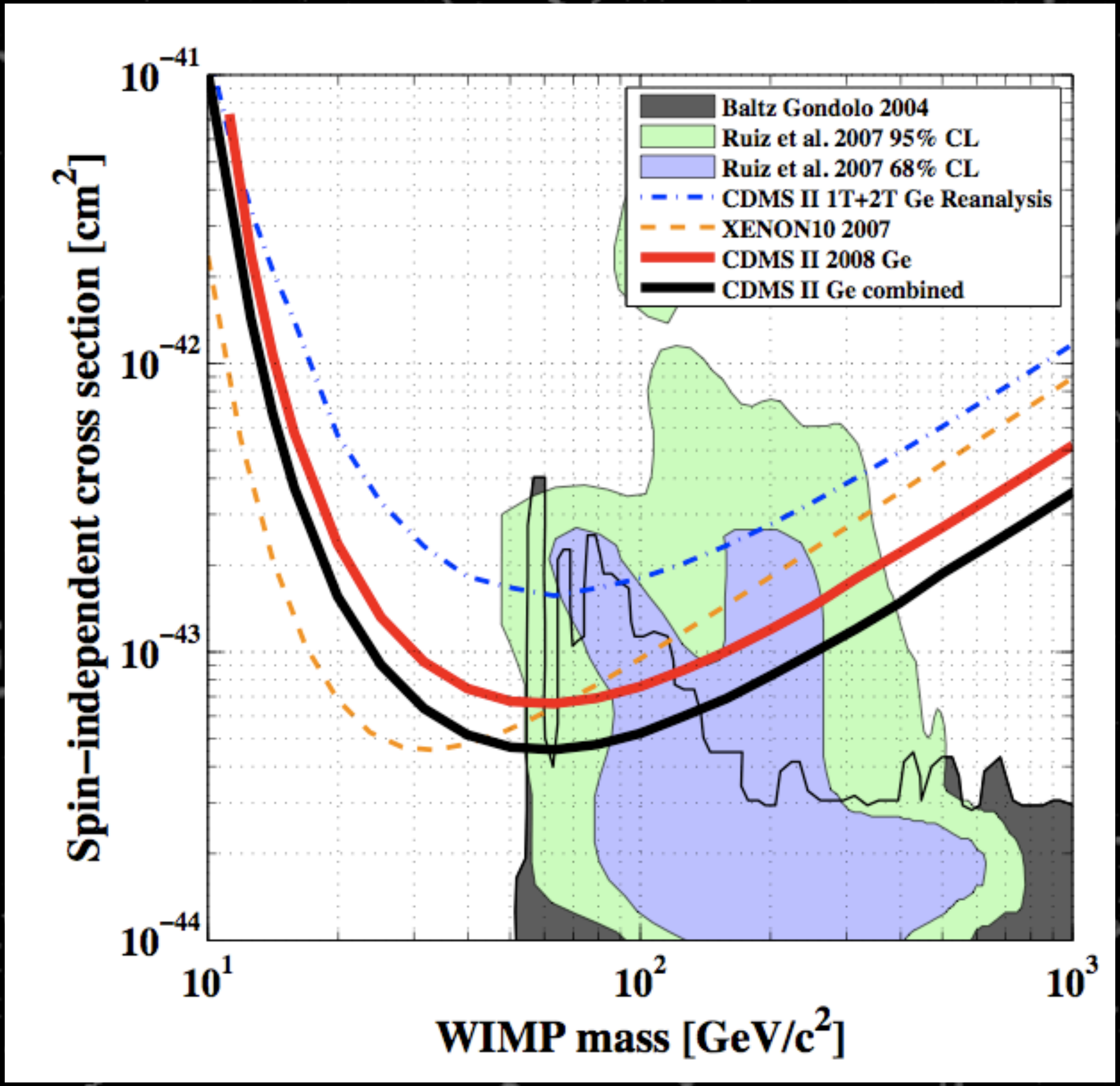


2e- of noise corresponds to 7.2 eV for ionizing energy!!!



What do you to with these CCDs when it is cloudy?

Dark Matter search

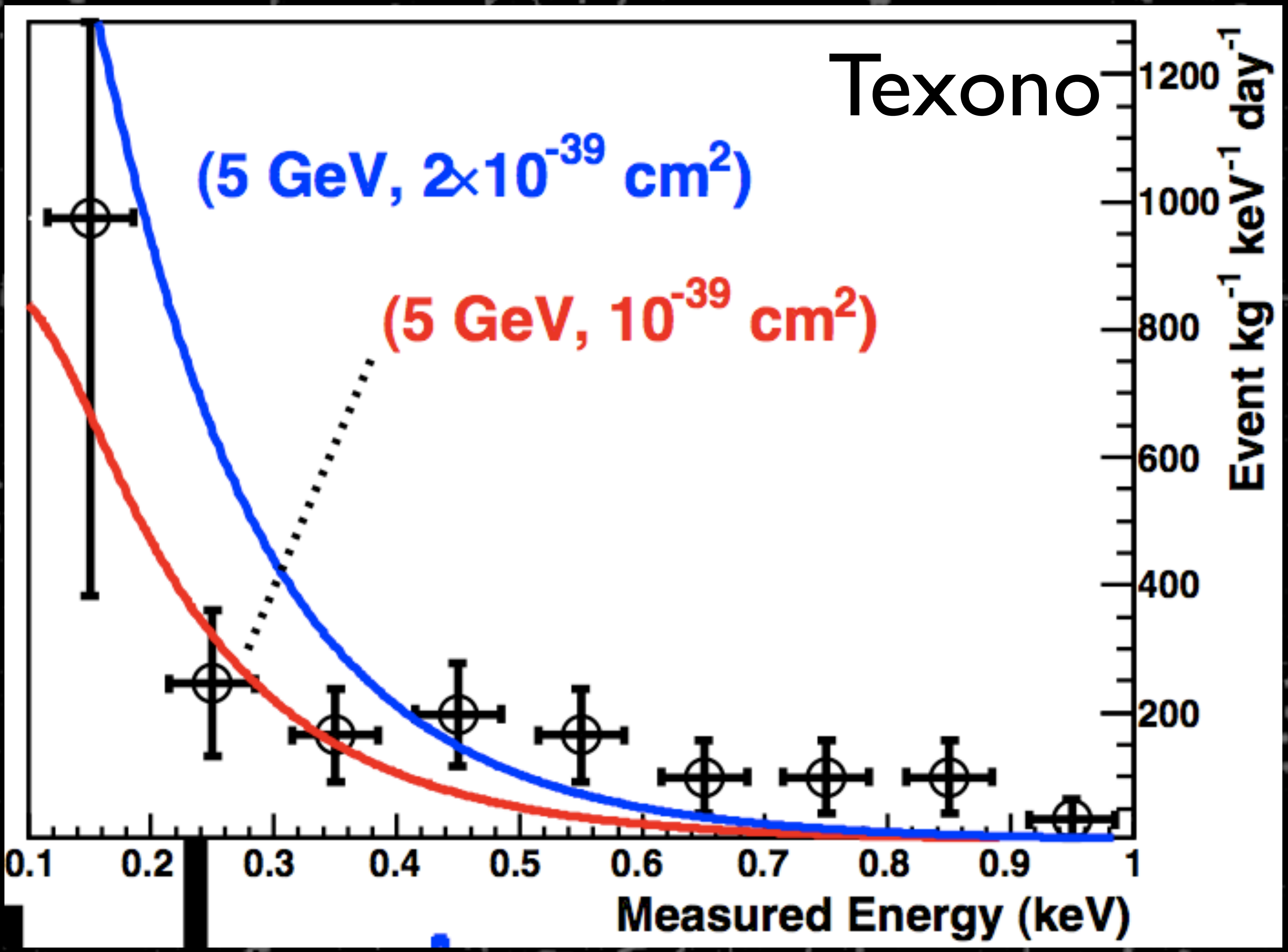


Dark matter searches usually look for nuclear recoils in a low background detector. Typically the threshold for such recoils are a few keV. For this reason the searches are not as sensitive for low mass dark matter candidates.

One of the limitations for low threshold searches is the electronic readout noise. A few experimental programs are trying to reduce the noise in their detectors to be able to set lower thresholds.

Due to low readout noise and relatively “large mass” (1 gram per detector). We are considering DECam CCDs for this.

Nuclear recoil spectrum



Example of the nuclear recoil spectrum for a 5 GeV WIMP using standard halo model.

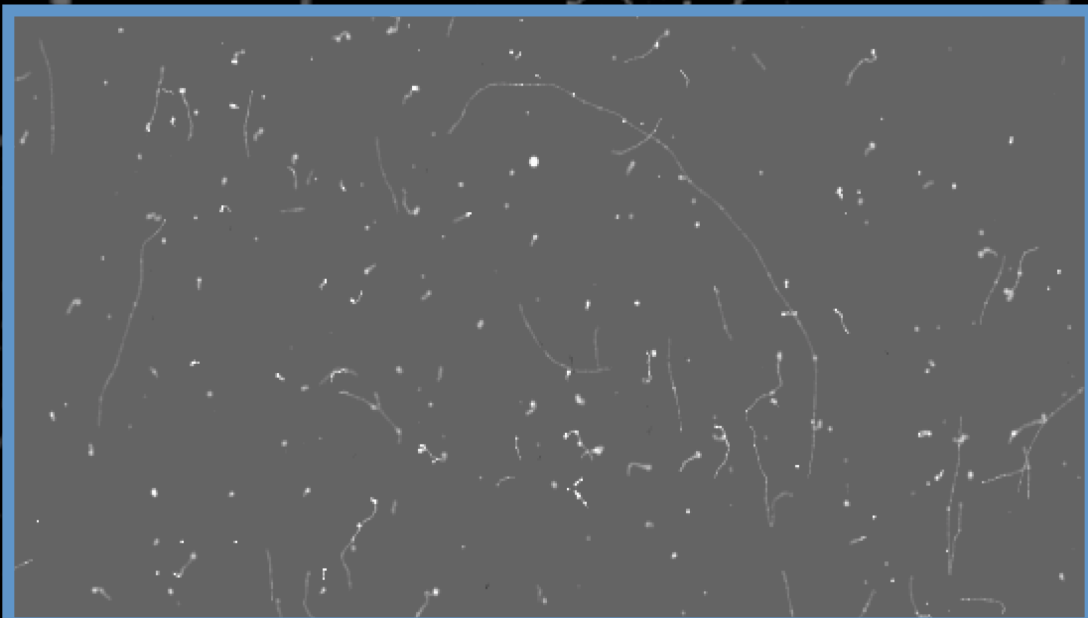
Three things to note:

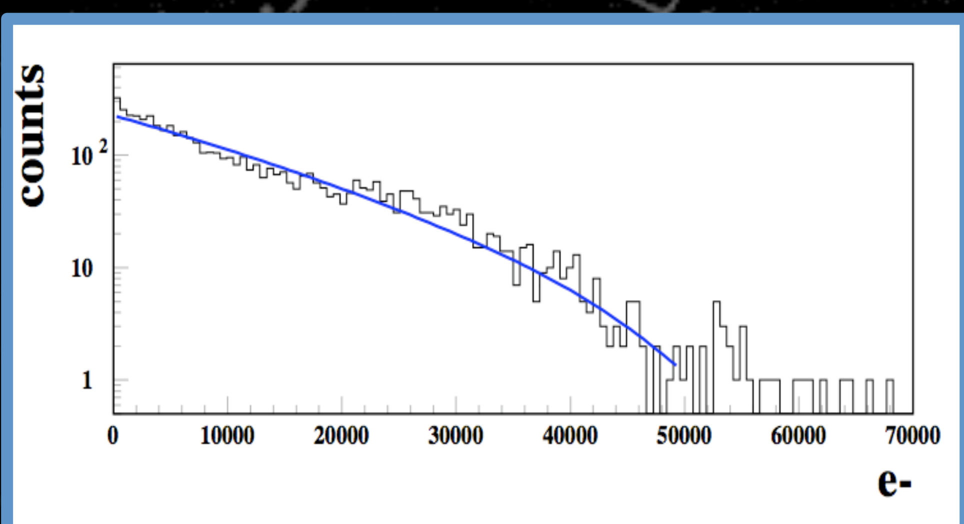
- need low threshold
- for a very low threshold you do not need such a large mass.
- Need background below 100 ev/(kg keV day) @ 0.5 keV to be sensitive to this signal.

- We could set a threshold at 36 eV in this scale, if we are limited by electronic noise only (5 sigma).

“Calibration” with Neutrons

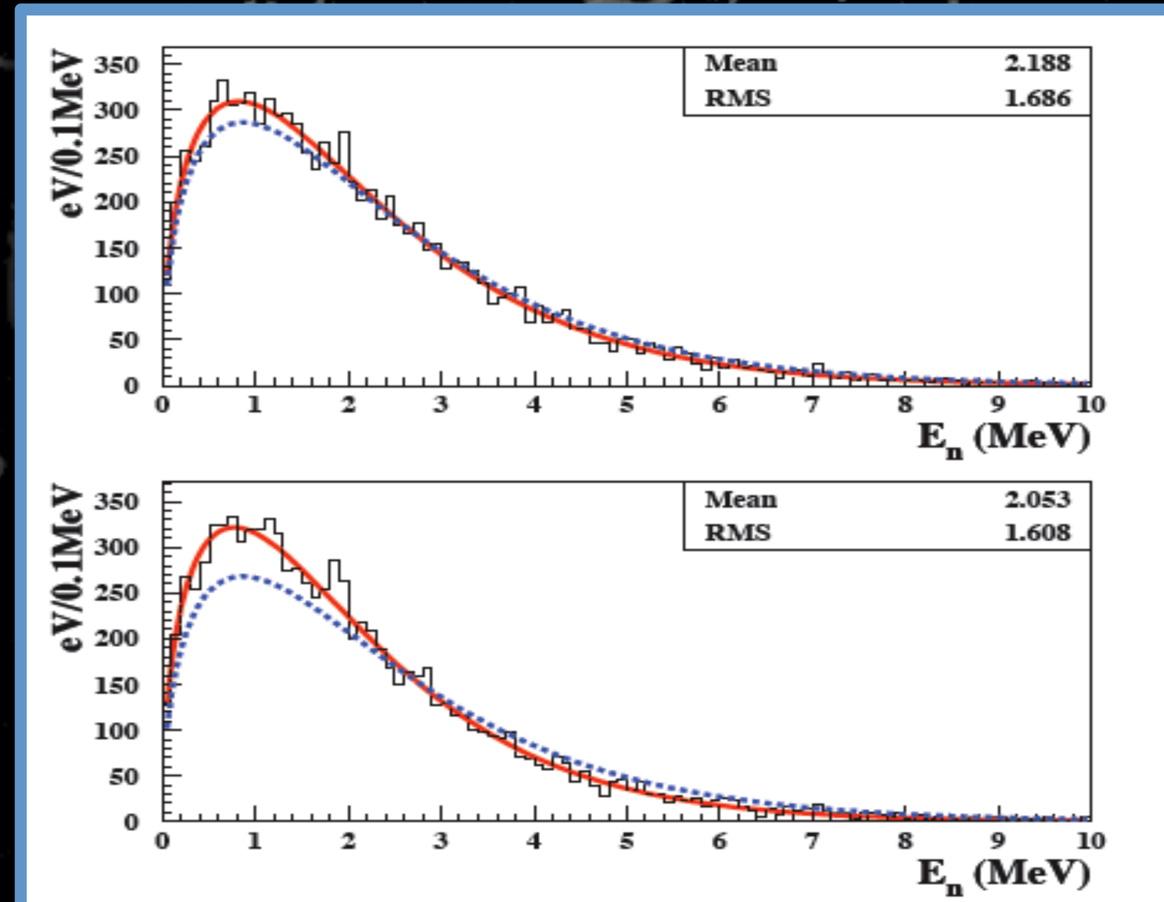
Neutrons ^{252}Cf





wall thickness	Vsub	f (e/MeV)	χ^2/n.d.f.	Q
2.5 cm	80 V	74083 ± 1034	2.6	3.71 ± 0.05
5 cm	80 V	68934 ± 1047	2.7	3.98 ± 0.06

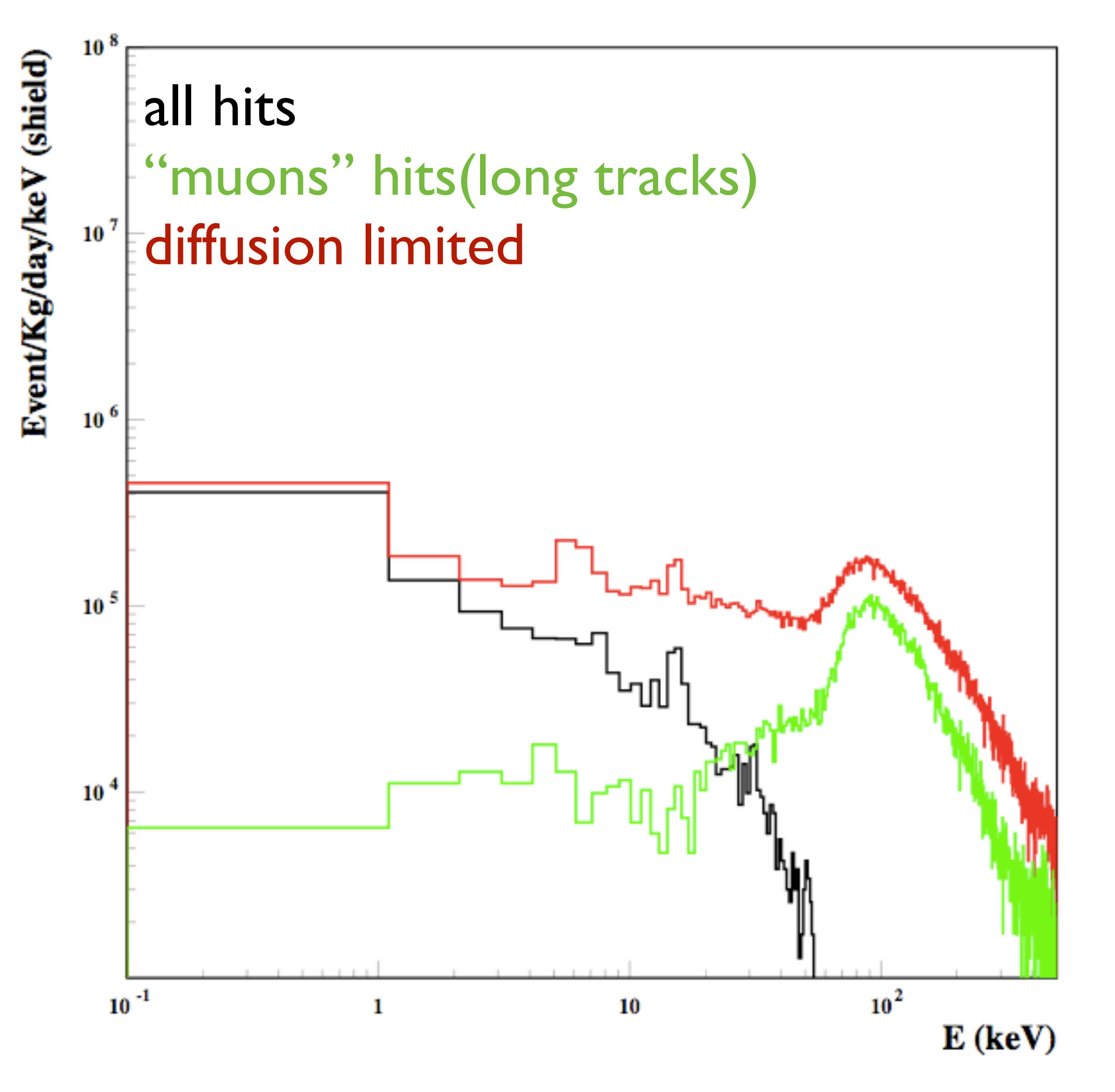
TABLE III: Parameters for the polynomial fit to the nuclear recoil spectrum in Fig. 8. The results assuming a 5cm thick wall are also presented.



Nuclear recoils have different charge yield than photons. New calibration required.

We measured nuclear recoils from a neutron source and fitted an ionization yield of ~13.9 eV/e- . This is not a real calibration because we can not fit the energy dependence of this yield, but the result is consistent with previous work.

The readout noise is Ok, what about the radioactive background? Detector at the surface in a FNAL building and with 6” lead shield.

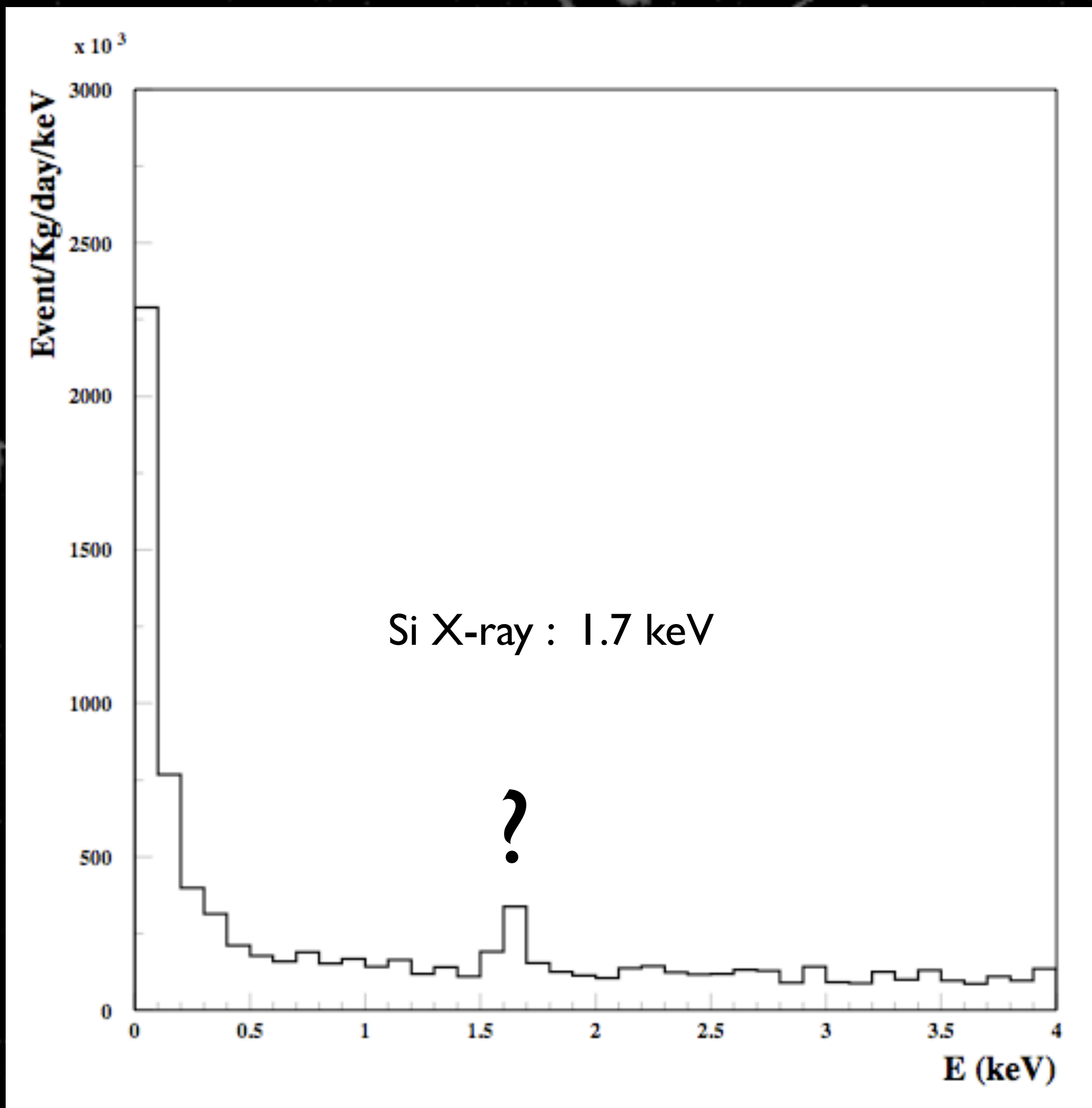


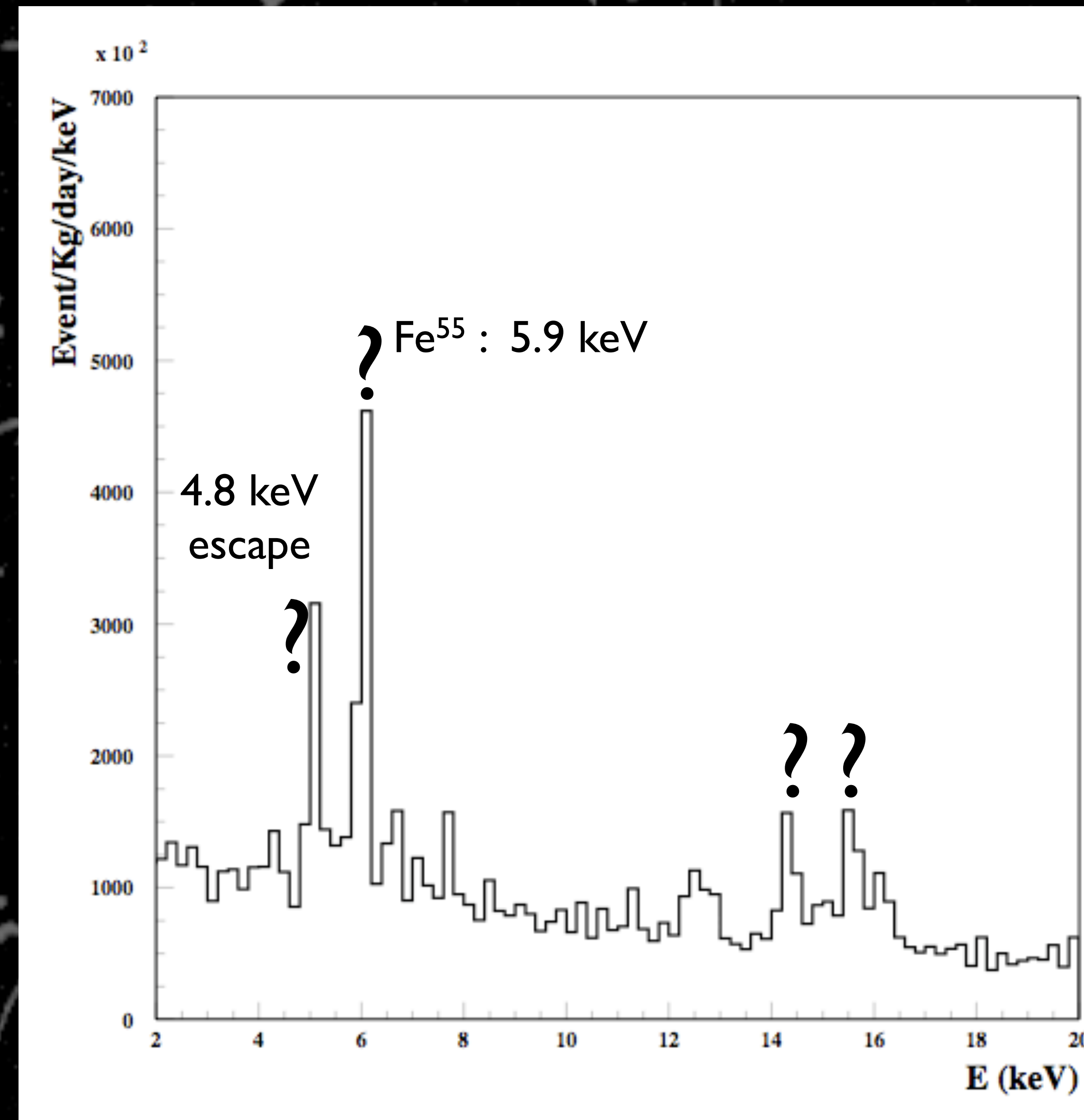
Need to reduce the rate by a factor of 5000 before we become competitive.

Later we discovered, with a Germanium detector, that the lead in the shield had been activated with high energy protons. Not a good shield.

New shield + going underground should do the trick, if we did not put anything to hot in the cryostat.

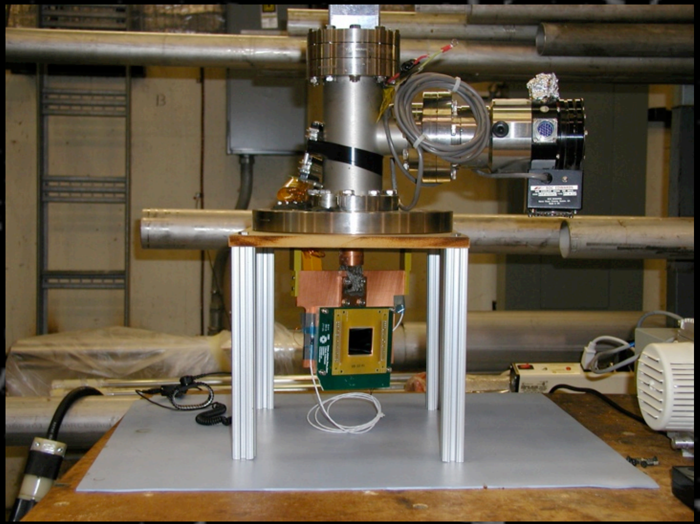
background spectrum



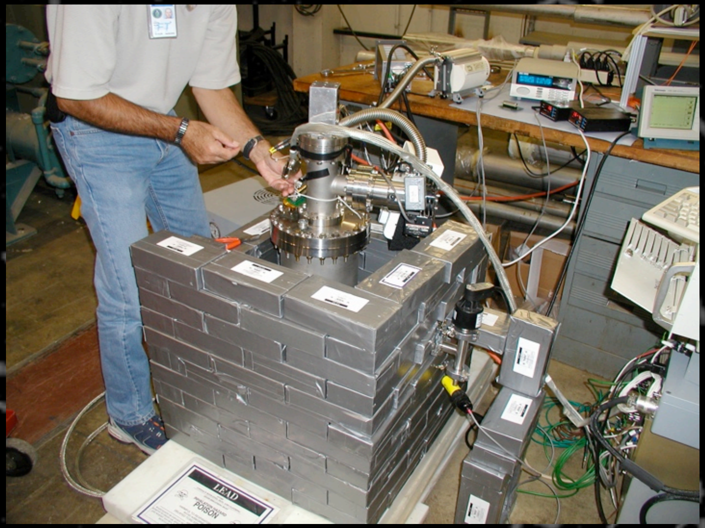


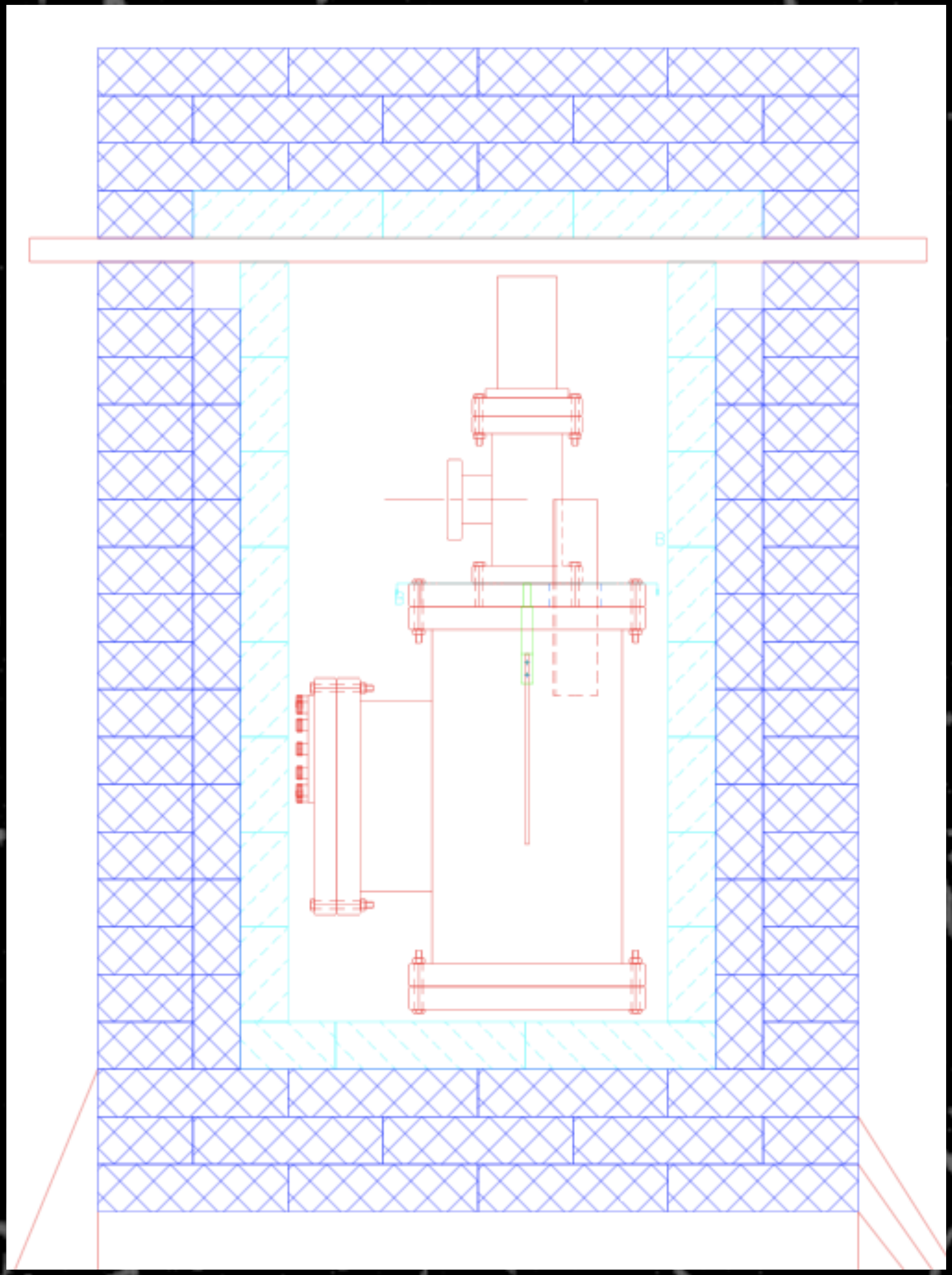
a few lines to investigate. These lines are not a problem for low background experiments, you just what to know what they are and the avoid using that region of the spectrum.

Dark Matter Experiment with CCDs



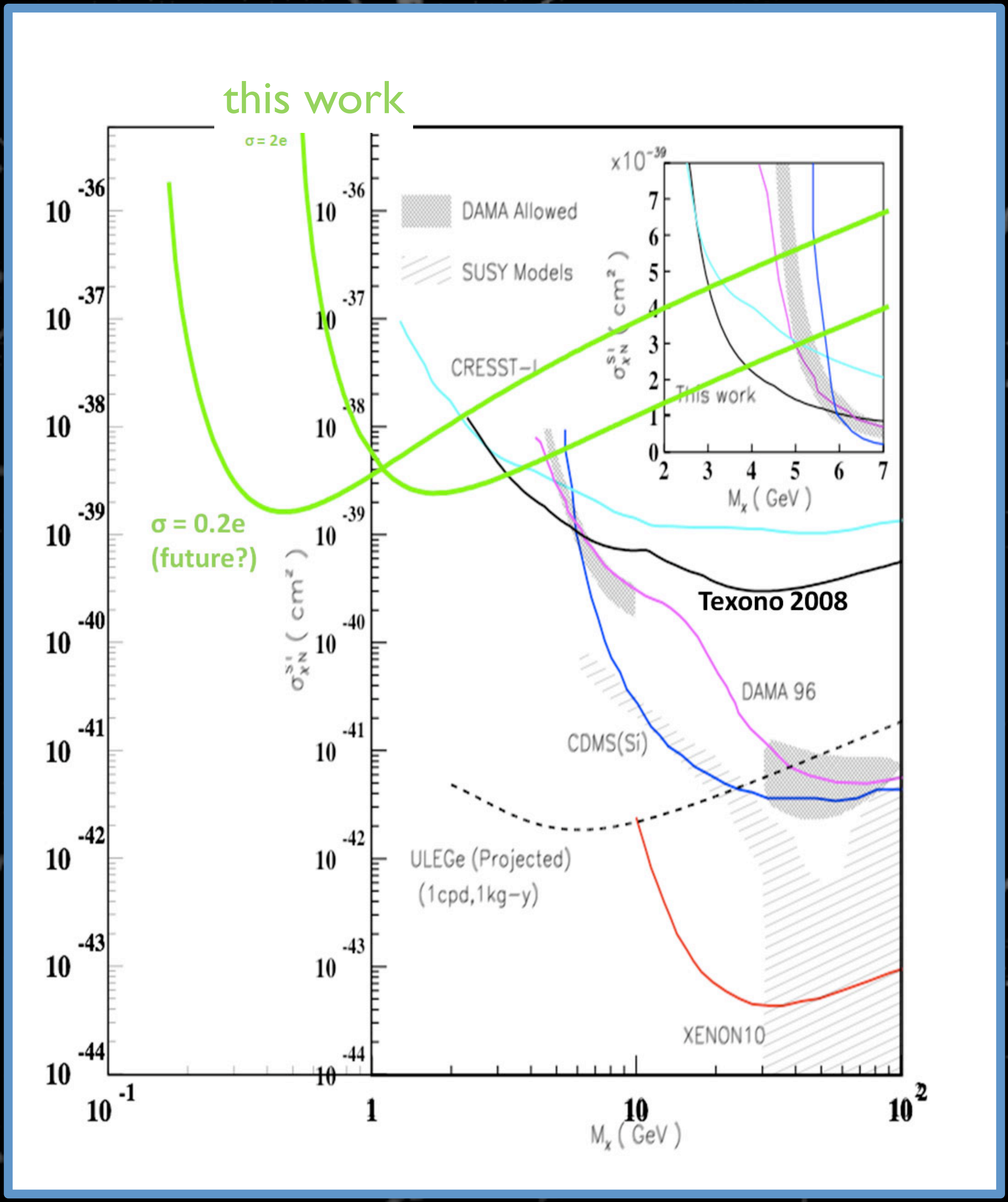
we have the dewar, the detectors, the electronics and we are building the new shield





each CCD 1g (2.4 g also available)
10 gram detector achievable soon and a 300 g-day exposure possible.
Plan: try 8” lead shield in Minos hall (350 foot deep) with a 10 gram array this year.

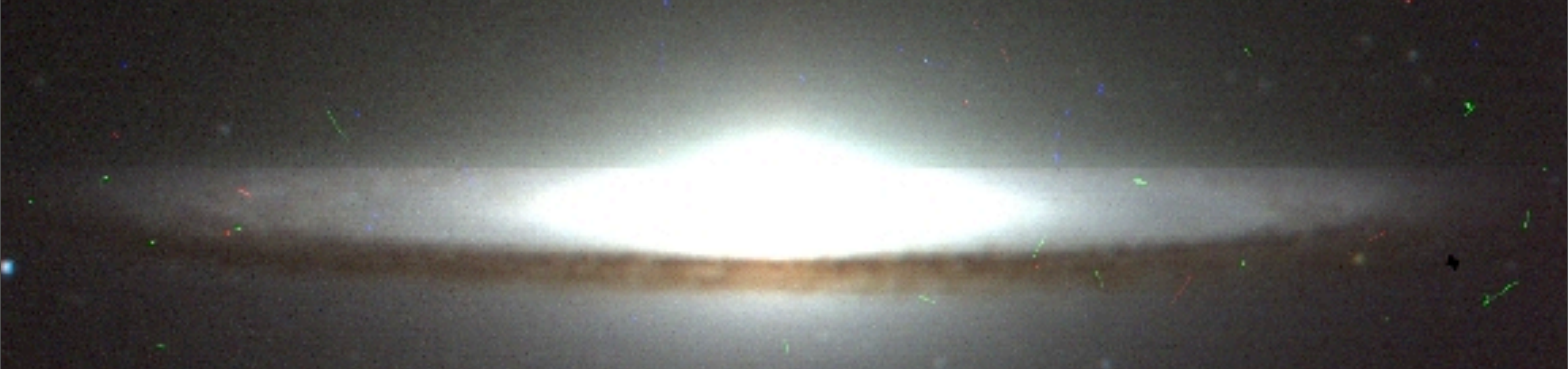
Prospects



Expected reach if we reduce the background by 3 orders of magnitude and accumulate 300 g-day of exposure. (Threshold 36 eVee)

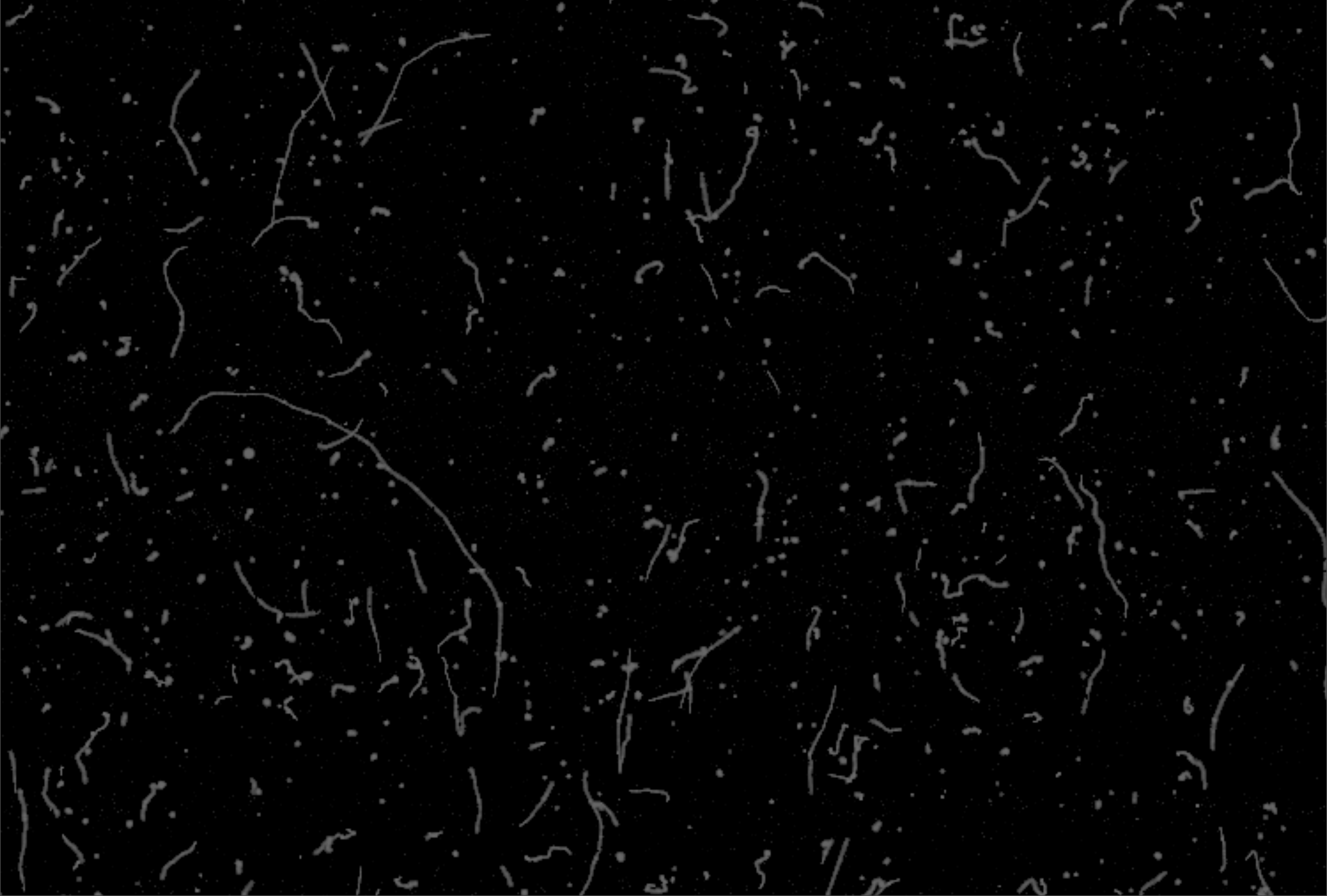
Disclaimer:
Not shown in this plot results from PPC Germanium detector (arxiv:0807.0879). They are expecting to get to thresholds of 100 eV soon.

“massive” CCDs for developed by LBNL will be used at DECam with improved QE in the near infrared. These detectors satisfy all the requirements for the Dark Energy Survey. Here an example image from a prototype camera with one of these detectors.



The detectors also present the opportunity for a new low threshold dark matter search. First underground test of the technology at FNAL during 2008.

The end



Cluster Counts (goal #1)

The distribution of the number of clusters as a function of redshift is sensitive to Ω_Λ and w.

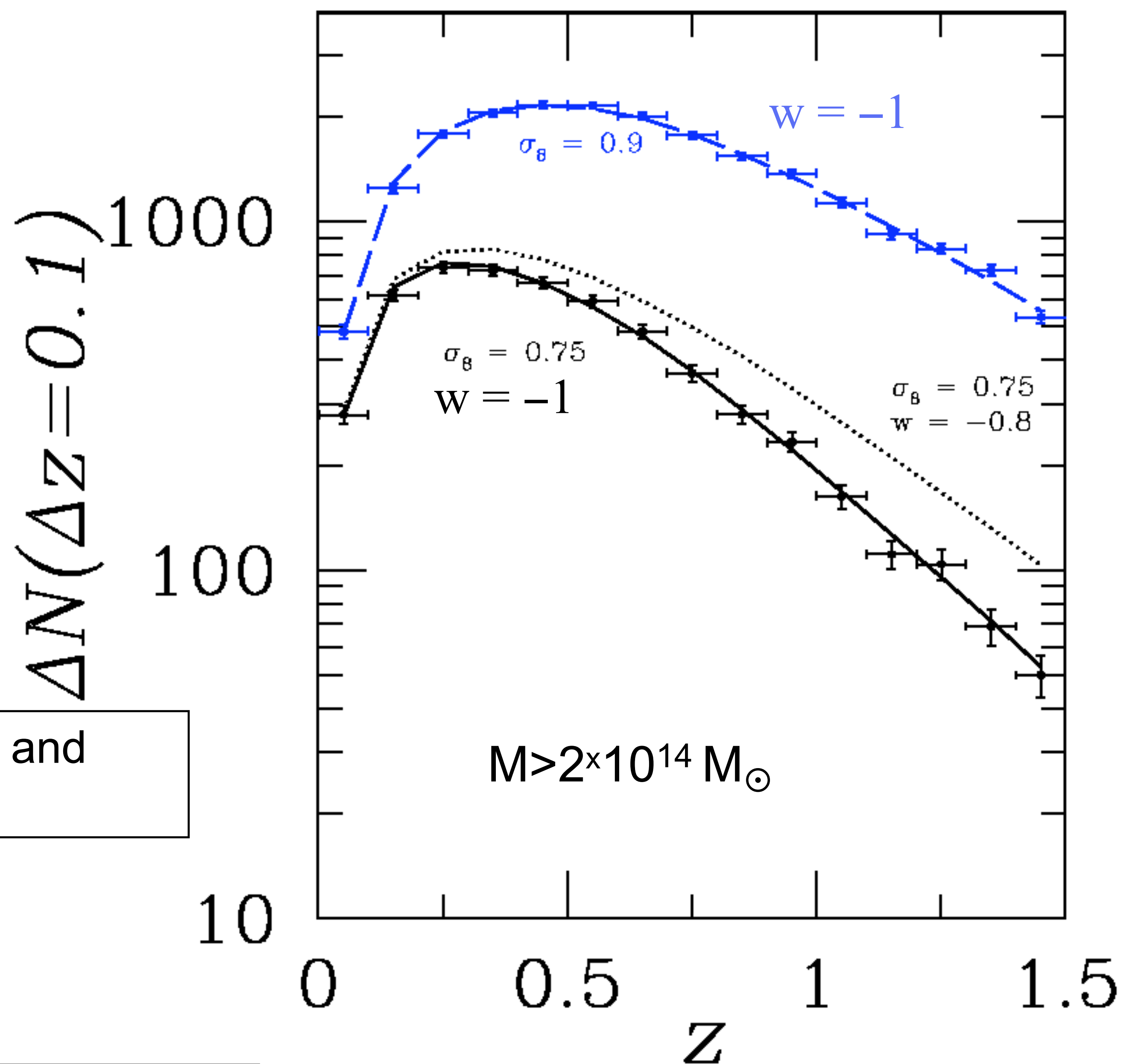
$$\frac{dN(M)}{dz d\Omega} = \frac{dV}{dz d\Omega}(z) n_{co}(M,z)$$

Volume: distance meas. Expansion history of Universe. **Geometry**

Abundance evolution: **growth of structure** and initial mass power spectrum.

Mass selection also has cosmology, for example luminosity distance.

Number of Clusters vs. Redshift



Forecast

Assumptions:

Clusters:

σ_8=0.75, z_{max}=1.5,

WL mass calibration

BAO: ℓ_{max}=300

WL: ℓ_{max}=1000

(no bispectrum)

Statistical+photo-z systematic errors only

Spatial curvature, galaxy bias marginalized, Planck CMB prior

In terms of the DETF:

Factor 4.6 improvement over Stage II